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IMPORTANCE AND ASSESSMENT OF DISCARDS IN COMMERCIAL FISHERIES

by

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Rome, October 1983

PREPARATION OF THIS DOCUMENT

This document has been prepared at the request of the FAO Fisheries Department (Fish Resources and Environment Division). The importance of discards has been emphasized in the last few years, but the hard data on discarding practices are scarce. This document is intended as a manual which could be used as a guide when attempting to estimate discards. It should still be considered a provisonal version and it is hoped that feedback from readers and field workers will help us to improve this manual which covers a rather neglected and crucial aspect of fishery science and stock assessment. The original draft was edited by J. Gulland, S. Garcia and G. Bazigos.

ABSTRACT

A review of the magnitude of the discarded catches from the major fisheries is made. Wide seasonal, geographic and gear-related variations were found in the discarded catch. Some simple field survey procedures for discard estimation are suggested. The probable biological consequences of discards are assessed on the basis of available information and suggestion for further studies are made. Some specific sampling and estimation methods applicable to the discard problem are suggested and some examples are provided.

W/Q 5329

For bibliographic purposes this document should be cited as follows:

Saila, S.B., Importance and assessment of discards in commercial fisheries. 1983 FAO Fish.Circ., (765):62 p.

FAO Fisheries Circular (FAO Fish.Circ.)

A vehicle for distribution of short or ephemeral notes, lists, etc., including provisional versions of documents to be issued later in other series.

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1. INTRODUCTION

The FAO report entitled "Agriculture Toward 2000" indicates that the anticipated world demand for edible fish and shellfish will, at constant prices double from the 1979 level of approximately 50 million t to about 100 million t by 2000. World fish production has remained at a relatively stable level for the past several years at about 70 million t of which about 50 million t are used for human consumption and about 20 million t for animal feeds. It is anticipated that the so-called harvest fisheries (conventional fisheries) may not meet this demand due to rising energy costs and other factors; that the full implementation of the needs will be met to some extent by aquaculture (the intensive culture of marine estuarine and freshwater organisms), and that the utilization of products now being discarded at sea must be substantially increased.

It has been estimated (Slavin, 1982) that the by-catch from the world shrimp industry alone (about half of which is discarded at sea) is from 3 million t to 5 million tons per year. The figure of about one-half for discards is suggested from Table 3 of the draft report of the "Workshop on the Scientific Basis for the Management of Penaeid Shrimp", Key West, Florida, USA, 18-24 November 1981. If one adds to this the more variable discards from the major demersal trawl fisheries and other marine fisheries, the annual quantity of fish discarded at sea is a very significant potential increment to the anticipated near-term future needs by mankind for animal protein.

For the purposes of this report, discards or discard catch refers to part of the gross catch not used in any way but is thrown back into the waters as whole fish or whole organisms (in the case of invertebrates, amphibians, reptiles or mammals). This phrase is not to be confused with offal from the retained catch, which might also be thrown overboard. The term by-catch is used herein to define that part of the gross catch which is captured incidentally to the species toward which there is directed effort. Some, all or none of the by-catch may become the discard catch.

The discard catch as defined above is almost always dead before being returned to the sea. Jean (1963) has conducted survival experiments with cod and American plaice off New Brunswick, Canada, and clearly demonstrated that survival is related to deck exposure time, temperature and size of the fish. Increased exposure time, increased temperature and smaller size groups all increased mortality. Little or no survival was evident after 45 min of exposure even at temperatures near freezing. De Veen, Huwae and Lavaleye (1975) have also provided some results of survival studies of European plaice and sole which indicated that:

(i) the degree of damage and subsequent mortality increased with the duration of the haul in the case of both otter trawls and beam trawls;

(ii) deck exposure of sole for 20 min gave low survival and 40 min exposures on deck caused complete mortality, and

(iii) undamaged plaice exposed for similar periods did not demonstrate additional mortality, but there was increased mortality of damaged fish from deck exposure.

Crean (1982) has made an analysis of the shrimp trawling operation and indicated that an average of 42.5 min was spent in sorting the catch and heading shrimp after which about 5.3 min were spent in clearing the decks. Typical tow durations for shrimp fishing may be from two to three hours or more. Such long tows are more damaging than short tows. Based on the above information, in tropical latitudes one may safely assume that virtually all of the discarded catch is dead prior to return to sea. Minor exceptions may include reptiles, such as turtles and sea snakes, or large fishes such as sharks, rays and conger eels which are sometimes deliberately discarded from the catch first in order to avoid possible injury to the sorting personnel. Some animals, e.g., crabs, may be active enough on deck to escape overboard through the scuppers without assistance.

Because edible species form a large part of the discard catch, social pressures are increasing in a protein-deficient world to either utilize the by-catch for food or animal feed or to reduce its magnitude by means of selective fishing gear in the belief that it would later be harvested by directed fisheries. There are several complex social, economic and ecological questions remaining to be answered concerning both of the above

mentioned alternatives. To date economic conditions have prevented some directed fisheries (i.e., penaeid shrimp fisheries in the Gulf of Mexico, for example) from landing more than small fractions of their by-catch due to the very great difference in price between shrimp and the fish by-catch, as well as limited storage space in vessels. Some selective fishing gear has been developed but the question of whether or how desired species (the objects of directed fisheries, such as shrimp) might be affected by selective gear which may favour relative survival of competing species remains largely unanswered to date.

In the case of trawl fisheries for demersal species, an examination of available data indicates that the rate of discarding fish at sea varies among species and gear types, as well as varying from year to year. There are many factors which can affect the selection of discards, such as the catch composition, when more valuable species are given preference over the lesser values species. Another factor may be the attitude of the skipper and crew toward handling small fish or gutting certain species. In addition, the annual fluctuations in year-class strength will influence to a great extent the age and size composition of discarded fish. This latter phenomenon has been clearly demonstrated by Jermyn and Robb (1981) in the case of North Sea haddock and cod. Finally, nets with different meshes or different gear types, such as, Scottish seines versus trawls or trawls equipped with rollers or tickler chains versus those not so equipped, will bring on board different proportions of small fish.

The seasonal, area, gear and annual fluctuations in abundance are factors also causing considerable variation in the rate of discarding of fish at sea from directed shrimp fisheries. However, in the case of the shrimp fisheries, a certain amount of progress has been made on reducing the fish and turtle by-catch in some commercial shrimp fisheries, notably in the pandalid shrimps of northern waters. Sternin and Allsopp (1982) review the literature on by-catch elimination strategies, and also suggest that pre-sorting of shrimp and fishes may also be possible for the penaeid fisheries by applying appropriate stimuli to induce escape reactions in fish, while leaving shrimp vulnerable to capture. Sound was considered by these authors to be the best potential stimulus. A successful sea turtle excluder device (TED) has already been developed (NOAA/NMFS, 1981).

Caddy (1982) has considered the by-catch in the management of shrimp fisheries with special reference to the Western Central Atlantic Fishery Commission (WECAFC) region. He projected five possible options for consideration, some of which could be implemented together. A brief statement of these follows:

(i) fuller utilization of existing by-catch, which also implies better understanding of by-catch population dynamics;

(ii) if directed groundfish fisheries exist or are planned in shrimp fishing areas, selector trawls are suggested for reducing by-catch;

(iii) mesh selection studies and proper mesh sizes for optimum yields are encouraged;

(iv) seasonal closures are suggested as management measures assuming proper background information is available to justify such actions, and

(v) management objectives should be better defined and related to the by-catch problem.

In general, it is clear that discarding is an important feature of world fisheries. Even the rough figures discussed above show that the quantities involved could be as much as 10 percent of the total world catch. Attention is now being turned to the various aspects of discards, especially in the tropical shrimp fisheries. Despite this attention, however, and the obvious need to know reasonably accurately how many fish, of what species, and of what sizes, are being discarded, quantitative information on discards is extremely scanty. This report has, therefore, been written to draw attention to the problem, and to provide some preliminary estimates of the magnitude of the discards, and guidance to methods of monitoring them, and determining the biological implications.

2. THE MAGNITUDE OF CURRENT DISCARDS

2.1 Shrimp Fisheries

Several estimates of the quantity of shrimp by-catch and the discarded catch from shrimp fisheries on a global basis have been made. These estimates vary widely for several reasons. Allsopp (1982) has tentatively suggested a by-catch to shrimp weight ratio of 5:1 for shrimp fisheries in temperate latitudes and a 10:1 ratio for tropical latitudes, as a rough guide for purposes of planning and extrapolation. Indeed, these ratios have already seen some utilization.

Slavin (1982) has summarized the available information on the magnitude of the by-catch in the shrimp fisheries. This summary includes a 5 million t-21 million t shrimp by-catch per year estimated by the US National Academy of Science, a 1975 FAO roundtable estimate of 3 million t to 4 million t of discarded catch from the shrimp fishery per year, and a 1980 review (Rome, FAO) suggesting about 5 million t per year. Slavin indicates a conservative figure of about 3 million t-5 million t per year for discarded by-catch.

However, Table 3 of the more recent report of the "Workshop on the Scientific Basis for the Management of Penaeid Shrimp" (Rothschild and Gulland, 1982) suggests that these figures may be somewhat inflated because the proportion of the by-catch discarded in southeast Asia and India appears to be very small.

Variation in seasons, bottom types, currents, time of day fished, behaviour of both fishes and shrimp and other factors contribute to variable shrimp to by-catch ratios at a given geographical location. There are also substantial differences in shrimp to by-catch ratios among large geographic areas. In those areas which have been systematically studied (Gulf of California, Gulf of Mexico, and the Guyana coast) these geographic variations are clear.

The shrimp by-catch has a variable size and species composition, usually consisting mainly of small demersal fish. In the gulf between the Arabian peninsula and Iran, at least 200 species have been reported from the shrimp by-catch. At least 100 species have been reported from the Gulf of Mexico, and the Gulf of California has a reported by-catch composition of 87 species. In most cases less than ten species make up about three-quarters of the catch. The average size of the fish found in the by-catch is usually quite small. Slavin (1982) has summarized some of the by-catch composition data. Studies in Guyana have indicated that the total number of species in the by-catch is relatively low but up to 52 percent of the inshore by-catch (less than 15 fathoms) consisted of marketable sized commercial species. Campos (1981) made initial estimates of shrimp: fish ratios in Costa Rican waters, and Turnbull (1982) has produced an excellent bibliography of shrimp by-catches on a global basis, which serves as a general reference document.

The world shrimp catch has remained reasonably stable since 1972 with a range of between 1.1 million t and 1.5 million t. Table 1a (modified slightly from Slavin (1982) indicates the major shrimp producing countries of the world. Shrimp production by continent with estimations of the extent of shrimp by-catch based on a shrimp to by-catch ratio of 1:5, are shown in Table 1b. More recent rough estimates of by-catch and discards in penaeid shrimp fisheries (Table 3 of the draft report of the "Workshop on the Scientific Basis for the Management of Penaeid Shrimp") are reproduced herein as Table 2b.

Not all the by-catch is discarded. There is a clear distinction between, on the one hand,the small vessels of most of south and southeast Asia, making daily trips, and which retain most of their catch, and on the other, the larger trawlers - for example the standard US "Gulf of Mexico" type - which make long trips, and where limited freezing capacity means that most of the by-catch is discarded. This distinction applies both between large geographical areas, e.g., between the western Atlantic and the Indian Ocean, and within countries (e.g., southern Java and West Irian within Indonesian fisheries), or between large and small trawlers in India.

A preliminary scaling of the total discarded catch has been made (last column in Table 1b). This suggests a discard total from the shrimp fishery approximating 3 million t. This figure is somewhat higher than that suggested in Table 2b. However, some regions

(i.e., the Gulf region between the Arabian peninsula and Iran, for example) are missing from Table 2b, with the exception of Kuwait.

Some interesting reports of discards from northern shrimp and other crustacean fisheries are shown in Table 2a. Some of these are isolated reports, but they suggest careful further studies. For example, the by-catch of significant amounts of young fish in the Antarctic krill fishery certainly bears careful study and further analysis. In addition, this table clearly points out that shrimp taken in northern latitudes also produce a relatively large by-catch, sometimes consisting of smaller specimens of the same species which are the objects of the directed fishery. Clearly effective management of intensively exploited species demands systematic information on the magnitude of the discards of small specimens of the target species, as well as monitoring data to minimize probable impacts on other species which are not a part of the directed fishery.

2.2 Other Fisheries

In the case of the by-catch from other fisheries, it is important to distinguish various types of discarded organisms. There are at least the following three categories of discards:

(i) non-target species:

This includes, for example, the dogfish Squalus acanthias in the catches of the US trawl fishery. They are discarded for the most part, inspite of the fact that the average size may be quite large and comparable to target species.

(ii) undersized target species:

This includes, for example, small cod in the directed fishery for cod, in the Northeast and Northwest Atlantic areas.

(iii) "Surplus" catches in "quota" fisheries:

This includes the indirect capture and discarding of species for which established quotas have been already filled. It should be noted that this problem has probably become greater since the advent of the zones of economic jurisdiction and stricter limits on catches by both local and foreign vessels.

The importance of quantitative information on the discrepencies between landings and the actual catch of a species has been recognized for some time by both fishery scientists and management agencies. Conclusions derived from stock assessments are clearly affected by the availability and reliability of information on discarding fish at sea. To this end an ICES resolution (ICES Council Resolution 1975/4:22) was adopted which stressed the importance of collecting discard data and of reporting these to the annual meetings. This resolution has prompted a series of reports at the annual meetings, and much of what follows is derived from these reports. In addition, the International Council for Northwest Atlantic Fisheries (ICNAF) also focused attention on the by-catch discard problem at about the same time, and reports from the Northwest Atlantic area have also been utilized.

It has been known qualitatively for some time that the discards of demersal fish from otter trawling, Danish seine and beam trawling operations under some circumstances represent a significant part of the total catch. However, the nature and extent of discards from other fisheries, such as purse seines, longlines, mid-water trawls, fixed traps, etc., is far less understood and has not been reported upon adequately.

Discard rates are highly variable between gears depending on their selectivity and mode of action. They can also vary within gears, to a smaller but still significant extent, depending upon the abundance of year classes, availability of other species, market demand and expected prices, among other factors. The obvious complexity of the interrelationships suggested above, does not offer much hope for obtaining accurate and precise estimates of the proportions discarded at sea, without carefully planned sampling experiments. However, some crude first approximations appear possible if one is willing to make certain simplifying assumptions.

Table 1a

Production of shrimp and shrimp by-catch in major countries
(from Slavin, 1982)

Country	Shrimp production (1978) t x 10^3	Shrimp by-catch ratio 1:5 t x 10^3
India	201	1 005
USA	192	960
Indonesia	139	695
Thailand	85	425
Malaysia	82	410
Mexico	67	335
Japan	60	300
Total		3 266

Table 1b

Production of shrimp and shrimp by-catch by continent
(modified from Slavin, 1982)

Continent	Shrimp prod. (1978) t x 10^3	Shrimp by-catch ratio 1:5 t x 10^3	Estimated percent discarded	Estimated discarded catch t x 10^3
Asia	714	3 570	10	357
Africa	30	150	50	75
Oceania	19	95	100	95
Europe	178	890	100	890
North America	303	1 515	100	1 515
South America	80	400	50	200
Total		6 620		3 132

Table 2a

Reports of discards from shrimp by-catches

Species	Gear	Location	Aver. % by Wt.	Range % by Wt.	Dates	References and Notes
Northern Shrimp Pandalus	shrimp trawl	Gulf of Maine	100	-	1973	Clark and Wood, 1978
Shrimp P.borealis	shrimp trawl	off Norway	50	40-60 seasonal	1980	Torheim, 1980
Shrimp P.borealis	shrimp trawl	W. Greenland	9	-	1976	Ulltang and Oynes, 1978
Shrimp	shrimp net	Germany	-	-	1978	Mohr and Rank, 1978 (jellyfish selection)
Krill Euphausia	net	Scotia Sea	-	-	1978	Rembiszewski et al., 1975 (significant amount of young fish in krill nets)

Table 2b. Rough Estimates of Bycatch and Discards in Penaeid Shrimp Fisheries[a]

COUNTRY	SHRIMP CATCH (1979) 1,000 tons	BYCATCH RATIO	BYCATCH TONS	% DISCARDED	QUANTITY DISCARDED	DATE OF OBSERVATION AND AUTHORIZATION
China[d]	7,500	8:1 - 4:1	35 - 60,000	nil	nil	October 1962
Indonesia (Arafura Sea)	6,000	variable 3:1 - 1:1 (inshore)	ca. 100,000	high	ca. 100,000	1970's (Unar)
Indonesia (other areas)	157,000	20:1 - 30:1 (offshore)	115,000	< 2%	< 2,000	
Australia	21,000	variable[b]	unknown	high	unknown	
Thailand	100,000	variable	750,000[c]	small	small	
India	183,000	4:1	316,000	< 2%	5,000	1970's (George)
Kuwait	1,600	10:1	15,800	95%	15,000	1978 (Mathews)
Senegal	5,500	variable	80,000	ca. 50%	40,000	1970's (Garcia)
United States (Atlantic coast)	105,000	2.8:1	37,000	ca. 100%	37,000	1970's (Pelligren)
United States (Gulf coast)		9:1	600,000	ca. 100%	600,000	1970's (Pelligren)
Mexico (Pacific coast)	46,000	10:1 - 15:1	400-500,000	> 95%	400,000	1970's and 1980's (Ehrhardt)
Brazil & Guyanas	21,500	10:1	215,000	high	200,000	Present (Villegas and Dragovich)
TOTAL	658,600		ca. 2,700,000		1,399,000	All Countries Above Except Australia

Total world landings, all types of shrimp 1,526,000
Total world landings (less pandalids, sergestids, etc.) 1,238,000

(a) All estimates are imprecise; the figures are presented here to illustrate the general magnitude of the quantities involved, and the regional variation.
(b) Bycatches are very low on schooling prawns, but can be high in other fisheries. Glaister reported bycatch of 21,700 tons (18,000 discarded) in the eastern Australia fishery that landed 2,500 tons of prawns in 1979.
(c) Taken as equal to the quantity of "unspecified marine fish" reported by Thailand in the Yearbook of Fishery Statistics.
(d) Yellow Sea fishery only.

Table 3 summarizes some of the available data on the proportions of the total catches which have been observed or reported to have been discarded at sea from diverse areas and by various gear types. It is evident from Table 3 that the proportion discarded is highly variable.

Table 3

Summary of discards taken from some available literature

Species Discarded	Gear	Location	Average % by wt.	Range % by wt.	Dates	References
cod	trawl	Gulf of St. Lawrence	6	2-9	1956-61	Jean, 1963, Table III
plaice	trawl	Gulf of St. Lawrence	26	13-51	1956-61	Jean, 1963, Table VIII
winter flounder	trawl	Gulf of St. Lawrence	5	-	1959	Jean, 1963, Table IX
silver hake	mixed	Gulf of Maine	100	-	1975	Anderson (MS) cited in Clark and Wood,1978
yellowtail flounder	trawl	Georges Bank	28	-	1961-77	Sissenwine(MS) cited in Clark and Wood, 1978
mixed	trawl	Greenland	13	-	1979	Reddin, D.G., 1980
cod	trawl	N.W. Atlantic	18	6-36	1980	Sinclair, 1980
shrimp *P. borealis*	trawl	off Norway	-	-	1977	Minet, Forest and Perodou, 1978 (4 000 t reported as fish by-catches)
haddock	mixed	Dutch vessels	21	2-143	1958-65	Daan, 1976
whiting	mixed	Dutch vessels	84	14-405	1959-75	Daan, 1976
haddock	seine	Scottish vessels North Sea	31	19-42	1975-80	Jermyn and Robb (1981)
whiting	seine	Scottish vessels North Sea	24	14-33	1975-80	Jermyn and Robb (1981)
cod	seine	Scottish vessels North Sea	9	4-13	1975-80	Jermyn and Robb (1981)
haddock	trawl	Scottish vessels North Sea	20	15-27	1975-80	Jermyn and Robb (1981)
whiting	trawl	Scottish vessels North Sea	19	10-28	1975-80	Jermyn and Robb (1981)
cod	trawl	Scottish vessels North Sea	0.8	0.1-2	1975-80	Jermyn and Robb (1981)

Geometric mean percent discarded by weight = 16.5 Arithmetic Mean = 26.99

n = 15

Jackknife estimate of variance, s^2 = 793.02

Estimated 95 percent confidence limits for arithmetic average of percentage discarded is 12.45-41.53

Also, although this table is not intended as a comprehensive review of all information, it does seem that the published evidence for the discarded by-catches from fisheries, other than shrimp is concentrated on the North Atlantic region. There is less published evidence for significant amounts of discards in other regions. However, some do exist. For example, Hatanaka (1979) describes the octopus fishery off West Africa, which is a highly specialized directed fishery. Fish caught as by-catch are discarded, but the magnitude of this discard loss is apparently not known. Discarding is a feature of many trawl fisheries, including the sea-bream fishery off West Africa and the croaker fishery in the Southern United States. Unfortunately, systematic studies of discards from these fisheries are not available.

Table 4 attempts to provide a preliminary estimate of the magnitude of discard losses from fisheries other than for shrimp. Specifically it is based on a list of selected species groups from the 1978 FAO Yearbook of Fishery Statistics, to which a geometric mean of the proportions discarded from Table 3 data has been applied. For purposes of obtaining conservative estimates, the geometric rather than arithmetic mean of the proportions has been applied.

The geometric mean is the N^{th} root of the product of N terms in a series, or

$$GM = \sqrt[N]{X_1 \cdot X_2 \cdot X_3 \ldots X_n}$$

$$\log GM = \frac{\log X_1 + \log X_2 + \log X_3 + \ldots \log X_n}{N}$$

The geometric mean (GM) is always less than the arithmetic mean, by tending to give more weight to the smaller variates, and less to the larger ones.

No discard losses are indicated for species groups 34 through 38 of Table 4 although it is known that some discarding occurs in these groups. For example, it is known that discarding is practised in herring trawling (Daan, 1976). A value, $^1/_2$ the geometric mean discard proportion was applied to group 39, miscellaneous marine fishes. The sum of the estimated discards calculated in the manner described above is about 3.6 million tons per year. It is thought to be a conservative figure, but it compares in magnitude with some estimated discards from the shrimp fishery on a global basis. It is also interesting to note that, according to this method of estimation, the fisheries for gadoids (cods, hakes, haddocks, etc.), comprising species group 32 contribute most to the discarded by-catch.

3. FIELD SURVEY PROCEDURES FOR DISCARD ESTIMATION

3.1 General Observation

This chapter attempts to acquaint the interested fishery scientist with some practical procedures for estimating the quantity of fish and other marine organisms discarded at sea by various types of vessels and fishing operations. Details of some of the statistical procedures are provided in appendices to this report. The reader will be directed to these sections from this description, which is considered an abridged "primer" of operational procedures.

The discarding of fish at sea is not a new phenomenon. It has been carried on for various reasons for some time inspite of the fact that published documentation on discard estimation and discarding practices is not abundant.

The overall level of discards depends, as was stated previously, on many factors, including the type of fishery. In mixed-species otter trawl fisheries, the capture of low market value species is virtually unavoidable, and these fish are often discarded at sea. Highly specialized distant-water fisheries for high value species appear to generate high proportions of discards, which are species caught incidental to the directed fishery. Examples of such specialized fisheries include shrimp and prawn trawling in several areas or trawling operations for cephalopods, such as off the coast of West Africa. It seems desirable to monitor the species composition of mixed fisheries, because changes in proportions and/or discard species composition may be indicative of changes in the fished stocks.

Table 4

Overview of possible discard losses by selected groups of species taken from the FAO 1978 Yearbook of Fishery Statistics - Table A-1

Species Group	1978 Nominal catch t	Discard to landing ratio	Estimated discards t
31 Flounders, halibuts, soles, etc.	1 211 819	0.165	199 950
32 Cods, hakes, haddock, etc.	10 450 295	0.165	1 724 299
33 Redfishes, basses, congers, etc.	5 215 530	0.165	860 502
34 Jacks, mullets,	8 175 009	0	-
35 Herrings, sardines, anchovies,etc.	13 517 814	0	-
36 Tunas, bonita, billfishes, etc.	2 522 332	0	-
37 Mackerels, snooks, cuttlefishes, etc.	4 056 728	0	-
38 Sharks, rays, chimaeras, etc.	605 839	0	-
39 Miscellaneous marine fishes	10 047 331	0.08	803 786
Totals	55 802 897		3 588 597

Of special importance to effective management of intensively exploited species is a sound knowledge of the proportion of the small specimens of the target species which are discarded at sea. Since these discards are invariably dead, they represent an additional (and perhaps important) source of mortality which must be taken into account for effective management.

3.2 Basic Steps

The following are considered to be important steps in any survey for discard estimation.

(a) Formulate the problem

From the above general discussion it is clear that an important first step in a field survey of discards is to identify the objectives in a formalized way so that any management planning alternative can be clearly evaluated with respect to its contribution to these objectives. The fishery scientist is not merely seeking information, he is seeking information which will eventually become part of the basis for some specific management decisions. It is therefore, very desirable to itemize the objectives of the survey, and to keep in mind the eventual decision process. For example, a survey designed to estimate the discard rates of small specimens of the target species in a highly exploited trawl fishery will probably require much more accuracy and precision than a general survey designed to estimate the present level of discards in a developing mixed species fishery.

(b) Define priorities

Because the extent of discarding varies with gear, season, target species,etc., it is unlikely that the discarding practices of all sections of a national fishery should be examined with equal attention. The practical significance of a given amount of discarding (as a percentage of the total catch) also varies. It may be more important to know about (and take action to deal with) five or ten percent of small individuals of a valuable target species discarded because of, e.g., the use of a very small mesh, or poorly framed regulations, than discard rates of 50 percent or 60 percent of trash species, with little alternative use. Before introducing a full-scale programme to determine discards (by sending observers to sea on commercial vessels, from logbooks, etc.), it is highly desirable to do a quick survey, even of a merely qualitative nature, to determine where the major discarding problems occur.

(c) Define the population

The objectives of the investigator determine the population from which information is desired - the target population. The target population may sometimes be different from that which is actively sampled. An example is the exclusion of some portions of the population which are too inconvenient to sample - say small vessel operations in remote areas. Upper limits can sometimes be constructed for the bias introduced by omitting such vessels, but usually some judgement must be utilized to evaluate the extent to which the sampled population mirrors the target population. This judgement should be documented in the form of assumptions and the uses for which the results seem appropriate.

(d) Specify precision

The specification of desired precision is an important step in survey design. It seems prudent to examine discard survey objectives with regard to the accuracy required in the estimates. If the estimates are to be used for comparisons, it does not make good sense to have greater precision than the standards against which comparisons are to be made. Some details about this sampling problem are presented in the Appendix 2.

(e) Construct frame and select plan

Constructing a sampling frame is to divide the population being sampled (in this case the total catches) into units (clusters, strata, and/or simple population units), such that every element of the population e.g., each vessel, or each fishing trip, belongs to one and only one unit. The frame is really an ordered list that facilitates unbiased selection. After some preliminary study the scientist should be able to identify characteristics of the population that can be used to design an efficient sampling procedure or plan. The selection of the sampling plan often involves cost considerations as well.

(f) Procure equipment

Before setting out to sea or sampling at ports it is desirable to have standardized forms and standard equipment for the sampling process.

A tentative checklist of sampling supplies and equipment includes:

- Suitable fish and invertebrate identification sheets or keys
- Length-frequency forms
- Fishing log forms
- Baskets, wire, ~ 20 kg capacity
- Baskets, wire, ~ 10 kg capacity
- Spring balance scales - for weighing filled baskets
- Pails, plastic
- Measuring board
- Clipboard
- Raingear and gloves
- Paper, pencils, etc.
- Formalin
- Preserving jars or waterproof plastic bags and specimen labels

(g) Design and print forms for recording data

Information which should be entered on suitable fishing log forms includes:

- Vessel name and registration number
- Gear and mesh sizes
- Date and time of sailing and return to port
- Date and time of tow
- Total time net was on bottom
- Position
- Depth
- Weights of retained catch by species

- Discard weights by species
- Notation on length-frequency samples taken for both returned catch and discards
- Miscellaneous observations

3.3 Direct Methods of Measurement

In the case of some established commercial fisheries (i.e., trawl fisheries) data on the fish discarded at sea can effectively be collected by members of the fisheries organization staff aboard commercial fishing vessels, if resources permit and cooperation is achieved. The areas sampled can be the same as those used for the routine sampling of landings in the fish markets. The objectives of the sample survey should include sampling each major fishing area at least once during each seasonal period for each of the major gear types used in the fishery. In temperate latitudes this involves quarterly samples at a minimum, but in the tropics it may not be possible to distinguish more than three major seasons and sampling at one-third year intervals would then be considered minimal.

Estimating the quantity of each species discarded will depend both on survey objectives, as well as the ways of handling the catch by the crew of the vessel sampled.

(a) Unsorted catch - scientific observer on board

If the catch is available on deck prior to any sorting, it is desirable to fill baskets or plastic buckets from the unsorted catch for analysis. The investigator is attempting to obtain a random sample from the trawl haul. Thus, he should try to avoid bias by taking at least three subsamples from different locations in the pile of fish - including all fish from top to bottom, which are combined in a suitable basket (e.g., bushel basket, $\sim$ 40 kg) for determining species composition. Similar procedures should be used for large piles of single species to estimate discards. Replication in both cases is desirable. Total discards should be measured on a basket (40 kg) basis using the sampling baskets provided, if possible. In the case of large catches it is not feasible to tally the total discards on a basket basis, and the captain or fishing mate's estimate should be utilized. The relative percentages of species discarded as obtained from the basket sample may then be applied to the total number of baskets discarded to provide an estimate of the total number of baskets discarded by species.

If discard data are not available for certain tows (i.e., the sampler is off duty), an overall estimate of the trip may be obtained as:

$$\frac{\text{Total hours fished (all tows)}}{\text{Hours fished (on-duty tows)}} \times \frac{\text{species discard}}{\text{(on duty tows)}} = \text{total discarded}$$

On some cruises, especially when catches are high, discarded fish are not boxed and might not be sampled. Therefore, estimates of the total quantity discarded must be made visually by the observer, or by a reliable crew member. In this instance, it is necessary to estimate total catch, total discards, and total retained fish for each haul. At the end of the trip the estimated weights of the retained fish on each haul are aggregated and compared with the actual weights landed. The discards are then adjusted by the ratio:

$$\frac{\text{estimated total fish retained}}{\text{actual weight of fish landed}}$$

This is based on the assumption that the discard estimates will vary in the same way as the retained fish estimates.

(b) All fish boxed - scientific observer onboard

If it is normal practice to box all fish, both those to be landed and those to be discarded, the observer can obtain an accurate count of the numbers of boxes discarded. If the number of boxes is high, a representative subsample is taken for detailed recording of species composition and other data as required.

3.4 Other Methods

It is sometimes difficult or even impossible to directly estimate the volume of discarded organisms by sending an observer out to sea. An example of such a situation is a small artisanal fishery consisting of vessels which could not accommodate an additional observer.

Where the discards are small individuals of commercially valuable species, the quantity discarded may be estimated by comparing the composition of the landings (medium and large fish only) with those of the catches (including all sizes of fish). Hillis (1981) has developed such a method of discard estimation which eliminates the use of observers at sea, but one which is suitable only for certain conditions. It can be used only when a portion of the gross catch (assumed to be representative of the total catch) is unsorted and returned to port. Length frequency distributions of the catch, landings and discards by species are required. Hillis developed a computer program which determines the factor by which the sample of discards can be adjusted so that after transformation, the shape of the length frequency distribution of discards plus landings will, as nearly as possible, match that of the catch. Obviously, this method does not apply to situations where some species are totally discarded. Further details on the application of this technique are found in the part of the Appendix entitled "Hillis' Method".

A similar indirect method for estimating discard rates is based on research vessel survey catches. However, it is a complex technique and is appropriate only under special conditions. Mayo et al., (1981) have developed a technique for stimulating the escapement and discarding of fish from otter trawls. Catches initially obtained by research vessels using small mesh nets were adjusted in stages to account for the large mesh sizes of commercial trawls, the discards of small fish and fishing power. Brown, Brennan and Palmer (1979) have also used a linear programming algorithm to simulate by-catch effects on mixed species management.

The fishermen themselves are a potentially valuable source of information on discards. At the simplest, this involves no more than talking to the fishermen as they land their catches, or at some other suitable (and possibly more social) occasion while they are ashore - which, discards apart, should be an essential part of any biologist's study of a fishery. At the least, these conversations are invaluable in planning priorities for more detailed investigation (see 3.2 (b) above). In most cases more quantitative information will be needed; for this logbook completed by the fishermen themselves can be invaluable.

Fishermen's logbooks are being increasingly used, e.g., in collecting statistical data on fishing effort, and position of fishing. Information on discards should be as far as possible incorporated into existing logbooks. In any case, emphasis should be on simplicity, and ensuring the willing cooperation of the fishermen. Even with good cooperation it is likely that the fishermen's estimates of the proportion discarded will be variable and have some bias toward underestimation. This bias can be detected, and largely removed if a few direct observations, from scientific observers at sea, can be made of the true discard rate. This is most efficiently done (in the statistical sense), by the use of Regression Estimates (see Appendix).

3.5 Length Frequency of Discards

Length measurements should be taken from representative subsamples of the discarded organisms. Length-frequency sampling of the discards is especially important in the case of discards of smaller specimens of the target species. The quantity of fish to be sampled for length frequency analysis varies with the size of the fish. For the discards of unmarketable groundfish, for example, a minimum of two 20 kg basket samples is suggested, and for smaller fish it is believed that one 20 kg basket sample will suffice for each haul.

Normally, length frequency data are recorded on astrofoil strips or aluminum strips which are punched with a sharp pointed pick. These strips should be immediately labelled in the upper right corner (species, vessel, date, tow number, recorder) after use.

Measurements from foil strips can be transcribed to special forms for later automated processing in some instances. In any event, the punched strips easily translate into size-frequency distributions.

The general procedure for analysing length discard data is that each sample of a haul is raised to a total haul. The raised hauls are summed to provide a total discard length distribution for the vessel sampled. In a similar way, samples of the length distribution of the landings of the vessel are taken and raised to give a total length distribution of the landings. The discarded and landed length distributions are then summed to give a total catch length distribution.

Usually the sample of all discarded fish is weighed at sea, but the weights of individual species within the sample are not taken. The weights of discarded fish can be estimated by appropriate seasonal weight-length relationships. See Ricker (1975) for methods for determining suitable weight-length relationships.

By drawing curves of the proportion of the catch discarded plotted against length by species, the length at which 50% of the fish are discarded can be estimated. This 50% length will give a more consistent picture of discarding practices, and how these vary with, e.g., market demand, than the percentage of the total catch of the species that is discarded, which is very sensitive to the sizes caught.

4. THE BIOLOGICAL CONSEQUENCES OF DISCARDS

4.1 The Nature of the Discard "Problem"

The problem raised by discarding has often been seen as a single problem, that of the waste occurring when potentially good food is thrown over the side. This discard problem, which is essentially a technical and economic one - how can shrimp trawlers making long trips with limited freezing capacity economically handle the discarded fish when bulk greatly exceeds, perhaps by an order of magnitude, the shrimp catch; how can the great variety of species and sizes of fish in the by-catch best be converted into a saleable product, etc., has been addressed many times, most recently and comprehensively at a workshop in Georgetown, Guyana, 27-30 October 1981 (Technical Consultation on Shrimp By-Catch Utilization). This particular problem will not be considered further here, except to note that taking fish out of the sea can be one of the simplest and cheapest steps in bringing the fish from the water to the plate of the consumer, who may live a long way from the sea, and want a product that suits his traditional taste. The wastage in throwing back fish into the sea should be seen as no worse than the underutilization of some stocks (squids, mesopelagic fish, etc.), or the overfishing of others (whales, herring, etc.).

There are several other problems involved in discarding, for example the losses of future catches of larger animals through the discarding of small individuals, especially of the target species; the possible contribution of the discards to fish production and future catches as food for scavengers, or, after decomposition, increasing nutrients; the possibility that the discards represent the removal from the system of fish that are predators on, or competitors with, valuable commercial species.

The approach used in assessing these problems is to briefly examine a specific regional fishery for which some preliminary biological and ecological investigations of a broad nature have been initiated. Specifically, the Gulf of Mexico will be considered, utilizing reports of a workshop on the ecological interactions between shrimp and bottom-fishes (R.F. Sheridan and S.M. Ray eds., 1981) an energy flow model study by Browder (1981), some of the available literature and reports on Gulf of Mexico shrimp fisheries, as well as some models of interacting species as bases for projections. A method and an application of the method for empirical monitoring of shrimp to fish ratios has been described in the Appendix. This monitoring technique is believed to have ecological implications by providing quantitative comparisons over time of changes in discard ratios.

4.2 The Gulf of Mexico Shrimp Fishery

The problem of discarded by-catch and its fate and biological effects is not unique to shrimp fisheries. Discarding occurs in other fisheries whenever the gear is non-selective. However, the magnitude of the discards in the Gulf of Mexico shrimp fishery is sufficiently large to serve as an adequate model for examining biological consequences of discarding activities.

Penaeid shrimp, consisting mainly of three species (Penaeus aztecus, P. setiferus and P. duorarum) are the primary targets of a very intensive fishery in the Gulf of Mexico, which produces an enormous by-catch of demersal fishes (most of which are discarded). Estimates of the magnitude of the discarded shrimp by-catch vary widely. However, they may reach as much as 1 million tons per year. Blomo and Nichols (1974) estimated fish to shrimp ratios in the range of 1:1 to 7:1 with an average of 4:1. Based on this conservative ratio and a projection of recent landings of shrimp of 61 647 t by the US shrimp fishery alone, the estimated by-catch is 561 000 t. More recent studies (Gulf of Mexico Fishery Management Council, 1980) indicate that the fish by-catch may be as high as 14 times the weight of the shrimp catch. Caddy (1982) has calculated an unweighted mean shrimp to total by-catch ratio for the WECAF region of 1:8.04. There is considerable seasonal variability in the discarded shrimp by-catch ratios, due both to the habits of the fishes, as well as the geographic and temporal variability in the shrimp fishery.

The species composition of the shrimp by-catch has been systematically studied in the Gulf of Mexico (Pellegrin, 1982). Although there is considerable seasonal variability, the by-catch consists primarily of sciaenids, pomadaysids, sparids, synodotids, serranids and bothids, all commonly referred to as groundfish. Sciaenid fishes made up an estimated 75 percent of the directed groundfish landings during the period 1959-63 (Roithmayr, 1965).

In addition to discarding most of the shrimp by-catch in this region, Baxter (1973) estimated that the discard rates for undersized shrimp ranged from 22 to 45 percent by weight of the total shrimp catch. Discarding practices for small shrimp apparently are influenced by:

(i) market conditions;
(ii) availability of small shrimp;
(iii) methods of grading landings, and
(iv) minimum size regulations.

In the Gulf of Mexico, as well as in other areas where shrimp are harvested commercially by trawls, shrimp and demersal fishes of various kinds form important components of the estuarine-coastal shelf ecosystem. To the extent that information is available about them, it appears that these demersal fishes (especially the smaller species and juveniles of some larger forms) share similar habitats, may depend upon similar food sources and may be the prey of common predators.

Demersal fish clearly make up a large part of the presently unwanted by-catch of the shrimp fishery. Some of these are juveniles of commercially important species. Approximately 2 000-4 000 t of bottomfishes are harvested annually in this region by directed commercial fin fisheries and recreational fin fisheries.

These combined fishing operations pose several important ecological, social economic and political questions, many of which remain unanswered to date. Some of the ecological problems are related to:

(i) the biological fate of the discarded by-catch;
(ii) the ecological effects of the discarded by-catch, and
(iii) the possible effects on yields of bottomfishes and shrimp of the mortality in bottomfish stocks due to the shrimp fishery by-catch.

There are, of course, a host of other factors which might affect both shrimp and bottomfish yields, ranging from environmental fluctuations to habitat destruction and pollution effects to which Caddy (1982) has appropriately drawn attention. However, these will not be explicitly considered herein.

4.3 The Fate and Effects of Discards

The discarded by-catch serves as a food source for a variety of organisms. These include birds, fishes, mammals, reptiles, invertebrates (including shrimp), and microheterotrophs (bacteria and fungi).

Table 5 lists some of the published and reported observations of possible behavioural responses to discards, cf. fisheries where organisms appear to be attracted to a source of food. Although the reports on sea birds in Table 5 are few, anyone who has been out to sea in a trawler remembers how sea birds appear (as if by magic) when the net is hauled in and culling-discarding operations begin. The attraction of sea birds to discards seems common wherever in the world ocean this practice is carried out. It also appears that large fishes, such as sharks, may learn to follow certain vessels because they provide more or less regular sources of food. A comparison of discarding by-catch at sea with deliberate chumming clearly suggests that this activity (discarding at sea) will attract certain fish species - especially the larger predators. This also seems to be the case with predatory mammals as indicated by the reported persistent proximity of killer whales to tuna bait boats off Ghana (Table 5) which discard small specimens of their catch. The reports of the attraction of other mammals and reptiles (turtles) to food are plausible, suggesting that a wide variety of marine organisms can adapt to discards as a food source. However, the proportion of the global discarded by-catch consumed directly by these organisms is believed to be a relatively small proportion of the total discarded by-catch. This statement is supported by the fact that the total standing stock of some larger organisms (birds, mammals, reptiles) is very small compared to the weight of by-catch discarded.

If the discarded by-catch is not eaten immediately, it may be displaced spatially through wind induced water movements and by currents. The extent and nature of this displacement depends on several factors, such as water depth, temperature, hydrodynamic conditions, specific gravity of the discarded organisms, etc.

Some ecological effects of discarding fish and other organisms at sea have been adequately resolved. One of these relates to nutrient regeneration from discards as a stimulus for increased primary production. Browder (1981) has developed an ecological energy flow model for the Gulf of Mexico which answers this question, as well as some others. Specifically, Browder found that the rate of nitrogen regeneration from discards was four orders of magnitude less than that from other forms of organic matter in the environment, and three orders of magnitude less than that expected from animal excretions and the nitrogen input of rivers. Thus, nutrient regeneration from discards is inconsequential for increasing phytoplankton-based detritus as food for shrimp.

A second important conclusion from Browder's study was that the biomass of discards (even in this region of extremely high amounts) is several orders of magnitude lower than other potential food sources for shrimp, such as the benthos or plant-derived detritus. From this it can be concluded that discards probably do not appreciably stimulate the growth of shrimp directly, unless they were very strongly favoured by shrimp as a food source.

The third point from the energy flow model of Browder suggests that, unless potential predators select for small groundfish over shrimp (which seems intuitively unlikely), the rate of kill by shrimp trawling of small groundfish may approximately equal the rate of natural predation. Browder does not discount the possibility that shrimp trawling, as currently conducted in the Gulf of Mexico, may affect groundfish biomass and directed groundfish harvests, and this possibility is strongly supported by the work of Caddy (1982).

Browder's final point, as inferred from the model study, is that unless groundfish are selecting against shrimp relative to their biomass in the environment, groundfish predation on shrimp probably is on the order of three times their harvest rate.

A summary of the above suggests that:

(i) regeneration of nutrients from discards does not stimulate the growth of shrimp by indirectly increasing their food supply;

(ii) discards do not supply (at current rates) a significant food source that directly stimulates the growth of shrimp;

(iii) it is not known whether groundfish discards by shrimp trawling appreciably affect groundfish stocks or landings by the directed groundfish fishery, but this possibility cannot be discounted completely, and

Table 5

Co-occurrences and apparent attraction
of organisms to fish and shrimp by-catch discards

Attracted Animals	Fishery	Location	Reference and Notes
16 species of sea birds	trawl	Pacific Coast of USA	Wahl and Heinemann (1979)
killer whales	tuna bait boats	off Ghana	Kwei and Mensah (1979)
several species of sea birds 3 dominant species	trawl	off New Zealand	Vooren (1977)
young herring	light fishing for Clupeonella	Caspian Sea	Zakharyam and Teruni (1979)
porpoise	purse seine	Tropical Eastern Pacific	NOAA/NMFS (1981) (Porpoise dolphin associated with tuna shoals)
small cetaceans	shark gillnet	Australia	Bannister (1977)
large sharks	shrimp trawl	Guyana	Allsopp (personal communication)
turtles	shrimp trawl	Gulf of Mexico	Shoop (personal communication)
sealions, albatrosses, etc.	trawl fishery for croakers, etc.	Uruguay	Venema (personal communication)

(iv) predation by groundfish may have an appreciable effect on commercial shrimp stocks.

4.4 Interaction Between Species

Inspite of the considerable information already obtained from Browder's model study and the large volume of literature (see, for example, the recent symposium volume entitled "Predator-Prey Systems in Fisheries Management", H. Clepper ed., 1979) concerning competition and predator-prey relationships, several biological and practical management questions remain unresolved. Of these, an important one relates to whether the current practice of removing demersal fish, which may compete for food, increases the availability of food and/or space for shrimp to the extent that shrimp yields can be significantly increased. This problem is somewhat the converse of that addressed by Caddy (1982) who suggested that a relatively large proportion of the discarded by-catch may be potentially valuable but undersized commercial fish. He (Caddy) suggests approaches toward improving the survival of commercial fish making up the by-catch. The evidence at hand indicates a large amount of variation (spatially and temporally) in the proportions of commercially utilizable, but undersized fish in the by-catches.

Some light may be shed on the competition - interaction problem from a consideration of dynamics and stability of ecological systems found in the ecological literature. Mathematical models of complex systems, similar to those suggested by Browder (1981) have either to be unrealistically simplified (linearized) for general mathematical analysis or tediously explored by computer simulation for large numbers of combinations of parameter values. The accepted current theory of many species communities is a combination of empirical rules which account for some variability among real ecosystems, with intuitive extrapolations of concepts from simple competition and predation models.

Noy-Meir (1981) has recently explored the theoretical dynamics of competitors under predation by isocline analysis. The system which he carefully explored consisted of two competing species preyed upon by one common predator. Each prey species in such a system can also be interpreted as similar groups of species (i.e., with similar resource use and growth rates, for example). Thus, the analogy to competing shrimp species and small demersal fish species with man as the common predator seems reasonable. From the analysis of several model systems Noy-Meir concluded that even the simplest model system which combines competition with predation (exploitation) shows a rich variety of different dynamic behaviours, which are all possible and seem probable with different combinations of the biological attributes of the species involved.

Of special relevance to the possible effects of shrimp by-catch discarding or utilization of the by-catch species along with the shrimp, is a statement quoted from Noy-Meir (p. 283) as follows: "A predator and a competitor prey may co-act in both depressing the growth rate of the prey species concerned; but if predation reduces a strong competitor even more it may indirectly benefit the weaker competitor". Under the assumption that demersal fish may be stronger competitors (by virtue of greater motility, larger ultimate size and greater longevity), it is tentatively suggested that non-selective removal of high by-catches of fish along with shrimp may lead to higher sustained yields of the shrimp species. Obviously, this is speculative, but it does suggest that care should be exercised in developing and applying selector trawls for the shrimp fishery without further examination and continuing re-examination of the biological and economic costs and benefits to the entire ecosystem.

Jones (1981) has provided a detailed development of the simple stock production model to a two-species system with an explicit term in the equation for growth of each stock to account for the effects of other species. The state equations for stock p and stock q are given by Jones as:

$$\frac{1}{p}\frac{dp}{dt} = a - bp - cq - \hat{K}f_p \qquad (29)$$

$$\frac{1}{q}\frac{dp}{dt} = \hat{a} - \hat{b}q - \hat{c}p - \hat{K}f_q \qquad (30)$$

where Kf_p denotes the effect of fishing on stock p. If only the steady state ($\frac{dp}{dt} = c$) is considered, the right hand side of the above equations can be modified and expressed as a function of fishing mortalities on the two groups as:

$$Y = AF_p + \hat{A}F_q + BF_p^2 + \hat{B}F_q^2 + CF_pF_q \quad . \qquad (31)$$

Eqn. 31 represents contours of equal yield that form concentric ellipses with their major and minor axes inclined to the axes of either F(p), F(q). What can be demonstrated by this technique is that under conditions of strong or unequal competition the region within which the elliptical yield curves is valid, is reduced. This can be interpreted as indicating that the chances of one of the competing groups being eliminated is increased under unequal competition. This seems to agree with Noy-Meir's conclusions as well. If the assumption that shrimp are weaker competitors than the mixed groundfish species is valid, then there is some conceptual reason to believe that adverse effects in the shrimp fishery might occur from selective harvesting of shrimp by trawling without a major directed fishery for groundfish species.

APPENDIX 1

Sampling Methods: Some Basic Suggestions for Discard Estimation

1. INTRODUCTION

The material which follows is intended to provide a brief introduction to some sampling concepts, to provide some elements of sample design and to suggest some specific sampling methodologies with examples which are believed to be especially useful to fishery scientists interested in estimating the by-catch discards from various fisheries. This material is necessarily brief, and a limited familiarity with basic statistics is assumed. The interested reader is referred to the important contributions to sampling in fisheries by Bazigos (1974, 1974a), Pope (1956, 1978), and to the basic textbooks (Cochran, 1977; Sukhatme and Sukhatme, 1970; Sampford, 1962; Raj, 1968) and others for further background and detail. The inland fisheries sample survey manual of Bazigos (1974a) is considered especially useful for sample problems.

This Appendix is intended to provide an introduction which is a distillation of material from available sources mentioned above, and the author's limited experience with the by-catch discard problem. It is hoped that it will provide some basic understanding and encouragement, leading to more widespread applications in fisheries science of suitable techniques for estimating discard losses.

The basic motive of any sampling scheme (probability sampling) is to minimize sampling error for a given cost, or alternatively, to minimize costs for a given allowable sampling error. The selection in either case depends on the particular problem under study and the amount of prior information available. Some basic sampling methods available for use include stratification, clustering, sub-sampling (two-stage sampling), systematic sampling, ratio estimators, regression estimators, and sampling with unequal probabilities. Some sampling designs may find optimum solutions in complicated combinations of the above-mentioned methods. This material will cover only a few of the available sampling methods considered applicable in our studies.

2. SOME BASIC SAMPLING CONCEPTS

A sample survey is a vehicle for inductive reasoning. It provides for the transformation of observations of a part into conclusions regarding the whole.

Sources of systematic errors inherent in the obtained sampling data are called measurement (non-sampling) errors. These are errors of omission, commission and willful adjustment of observed information. These may arise from several sources. For the specific case of recording discards in fishermen's log books, measurement errors frequently arise from a desire to make things look diffferent than they are for tax reporting or other purposes. Statistically speaking, it is suggested that there should be a basic distrust of discard data recorded or analysed by anyone except the fishery scientist (and/or his staff) who will actually use the data. The fishery scientist will sometimes have to assess one level of accuracy of the obtained information by using his own quality check techniques. Sometimes, biased data (if affected by consistent measurement errors) can provide useful auxilliary information, as will be shown.

To be representative, it is necessary to specify that the sample reflect in proper proportion the various attributes of the population under study or to be obtained by using a random process of selection. Any formal consideration of the level of representativeness of a sample and accuracy of the calculated estimates involves such terms as population, distribution, bias and error. Some of these terms will be described briefly.

In the material which follows population parameters are described by Greek letters and sample statistics and denoted by Roman letters:

	Population	Sample
mean	μ (mu)	$\bar{x}$
variance	σ^2 (sigma)	s^2

The size of the population is N and sample size is n. An unbiased estimate of a parameter is indicated by placing a 'hat' over the parameter symbol. Thus, to say that a sample mean

is an unbiased estimate of the population mean is equivalent to the expression

$$\hat{\mu} = \bar{X}$$

A population of a characteristic is the complete set of values of the characteristic. Specification of the population of units requires definition in terms of the target population and evaluation of the units into which the population can be divided, and the boundaries of the population and the time interval during which information is relevant.

Populations of characteristics are defined by their distributions. If it is possible to categorize each unit in a population according to its value and graph the frequencies with which each category is represented, the result is a frequency diagram of the distribution. This provides some visual illustration of the population. The choices of category within such graphs is arbitrary. However, if the categories are made very small, the graph assumes the appearance of a smooth curve.

The frequency distribution of fish to shrimp ratios has been shown by Keiser (1977) to appear as in Figure 1. Clearly, this distribution does not conform to the typical bell-shaped curve which describes a normal distribution. Keiser transformed the ratios to base 10 logarithms and computed means and variances for the transformed data. Clearly, the mean so computed is a geometric mean and the confidence limits obtained in this manner are not symmetrical when transformed back to real numbers.

A sampling procedure is usually judged by the accuracy with which it reflects the population, or with which it estimates population parameters (such as the population average of discards). This accuracy is composed of two factors, sampling error and bias. The difference between the population average and the expected value of sample mean is due to bias in the sampling procedure. The dispersion of sample averages around their expected value is termed the sampling error. Figure 2 illustrates the sampling distribution of $\bar{X}$ for two different distributions of sample means superimposed on the parent population, shown by a dashed line in this case. Estimator B is unbiased, since its expected value is equal to μ, but it is not very precise. Estimator A is more precise because it has a narrower sampling distribution (i.e., smaller sampling error, but it is biased):

$$\text{Bias (A)} = \mu - A = 2$$

The most common measure of dispersion per unit is the variance, defined as the average of squared deviations of units from the mean. It is usually symbolized as σ^2, and σ, the standard deviation is the square root of the variance. A sample is some portion of the population composed of n units. Sample means and sample variances are called statistics because they are variables dependent on the particular assortment of n units chosen for the sample.

Being a variable, a statistic also has a distribution. This distribution is called the sampling distribution, since it reflects the frequencies with which the statistic would take on different values if the sampling procedure were repeated an infinite number of times. The expected value of a statistic is defined as the mean of its sampling distribution. Since the purpose of sampling is to obtain information about the population, one is generally concerned that the sample statistics are accurate estimates of the population parameters. As indicated previously, accuracy and bias have been characterized in terms of the sampling distribution. Sometimes a precise, slightly biased estimator (such as the ratio estimator to be described) is preferable to an unbiased but substantially less precise estimator.

Most unbiased sampling procedures require probability sampling. The requisites for probability sampling are:

(i) every unit in the population has a known probability of being included in the sample;

(ii) a sample is drawn by some method of random selection, and

(iii) probability of selection is taken into account when making estimates from the sample.

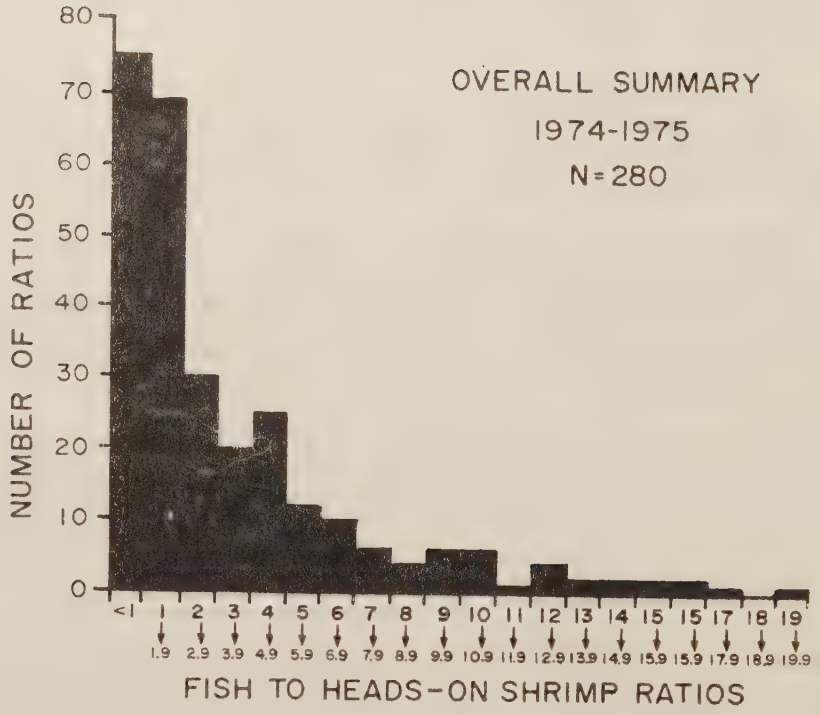

Figure 1 Distribution of fish/heads-on shrimp ratios (by weight) calculated from commercial shrimp catches, May to December 1974 and May to August 1975 (11 highest ratios not plotted). (From Keiser, 1977)

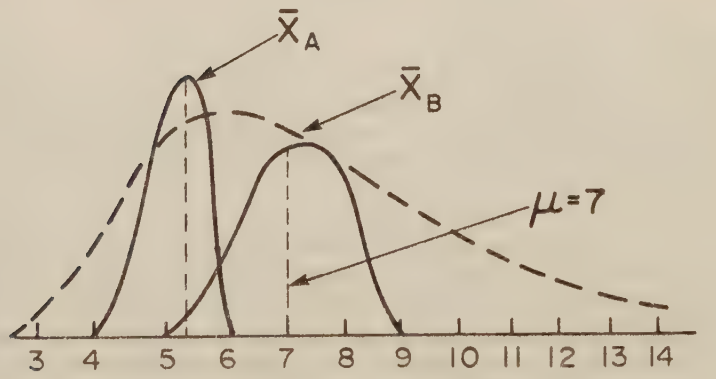

Figure 2 Example of a precise but biased estimate and a less precise but unbiased estimate of the population mean

The simplest probability sample is the simple random sample. The required conditions are:

(i) independent selection of sample units, and

(ii) equal probability of selection for all units in the population. A table of random numbers is one way to draw random samples.

3. ELEMENTARY SAMPLE DESIGN

Sample design involves getting the most accuracy for one's efforts, and it is a problem apart from that of obtaining "valid" results in the sense of being able to draw correct inferences. Validity derives from adhering to well-defined rules of good practice, such as using correct estimators and maintaining independent selection of sample units. A designed sample, on the other hand, seeks to utilize prior knowledge about the population in order to increase accuracy or decrease costs or both.

Precision is increased by decreasing the variance of the sampling distribution. There are four principal methods for achieving this. They include:

(i) increasing sample size;

(ii) stratifying the population;

(iii) using auxiliary variables in the estimator; and

(iv) using unequal probabilities of selection

A simple way to increase precision is to increase sample size.

Sometimes in sampling there is an opportunity to observe an auxiliary variable which is closely related to the variable of interest and which can be utilized in the estimation process to give more precise estimates. Two such estimators are ratio and regression estimators. Ratio estimators are considered particularly relevant for the purposes at hand and they will be discussed in some further detail, as well as illustrated by example.

4. BASIC TECHNIQUES OF SAMPLE DESIGN

The most basic of the techniques for sampling are those that partition the population so that the resulting sample will reflect some special knowledge of the manner in which the population units naturally occur. These techniques include:

(i) stratified sampling;

(ii) cluster sampling;

(iii) two-stage sampling (sub-sampling), and

(iv) systematic sampling

The above are frequently foundations of more complex schemes used in some applications.

In material which follows, the formulae for estimation of population means and variances are provided in Appendix 2 rather than being included in the descriptions of the basic designs. The reasons for doing this are to make easier reading for those interested only in the general rationale behind the design, as well as providing all computational formulae together for ease of comparison.

5. STRATIFIED SAMPLING

In stratified random sampling, the population is divided into non-overlapping sub-populations called strata. A simple random sample is then drawn from each stratum.

There are four prime reasons for stratification:

(i) it may sometimes be desired to obtain estimates for sub-divisions of the population;

(ii) it may be logistically or administratively convenient to break up the population into strata which are easier to work with;

(iii) sampling problems may differ in different parts of the population. For example, in sampling shrimp by-catch discards it would seem practical to put large refrigerated hold vessels and small "day" boats into different strata, since their trip length and probable fishing grounds are different, and

(iv) finally, and most importantly, considerable precision may be gained by dividing a heterogeneous population into strata that are internally homogeneous. Differences between strata do not contribute to the stratified sampling variance. Therefore, the smaller the variability within strata, the smaller the sampling variance.

The simplest way to allocate the sample is to use proportional allocation. That is, once the overall sample size is given, one makes the number of sample units drawn from each stratum proportional to the total number of units in that stratum. The gain in precision over simple random sampling in this type of allocation is entirely due to that prior knowledge of the population that led to its partitioning (i.e., the knowledge that the variances within strata are smaller than the overall population variance).

Proportional allocation overlooks two items of information that may sometimes be available to the fishery scientist. These are:

(i) differences in variance (σ_i^2) from stratum to stratum, and

(ii) differences in the cost (c_i) associated with observing a unit in each stratum.

The purpose of practical sampling is really to minimize both sampling variance and cost. Therefore, it follows that more units should be drawn from high variance strata where sampling is inexpensive. When the stratum sample sizes (m_i) are set proportional to their respective standard deviations (σ_i) and inversely proportional to the square root of costs (c_i), allocation is then called optimal allocation. If the fishery scientist is confident in his estimate of at least the relative magnitude of c_i and σ_i, optimal allocation is suggested rather than proportional allocation in stratified sampling.

APPENDIX 2

Sample Size for Simple Random Sampling

1. GENERAL

It is important to try to determine in advance the smallest sample size that assures the fishery scientist the desired precision of the estimate. This will be called the optimum sample size. The formulae for determining optimum sample size depend on how reliability is defined. Material which follows is largely based on Karandinos (1976).

Reliability can be defined in several ways. These include:

(i) the coefficient of variability of the estimate;

(ii) by a probabilistic statement where the confidence interval is equal to some percentage of a parameter, e.g., a fixed proportion of the mean, and

(iii) a confidence interval equal to a fixed positive number.

2. RELIABILITY DEFINED BY THE COEFFICIENT OF VARIATION

Let a random variable X have a distribution with mean μ and variance σ^2. Estimate the unknown μ by a simple random sample mean $\bar{X}$, where

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

The coefficient of variability of the new random variable $\bar{X}$ is:

$$C.V.(\bar{X}) = \frac{\sigma_{\bar{X}}}{\mu_{\bar{X}}} = \frac{\sigma/\sqrt{n}}{\mu} \qquad (1)$$

It is intuitively evident that the larger the n the greater the reliability of the estimate, and from Eqn. (1), the smaller the C.V. $(\bar{X})$. The method involves deciding arbitrarily on a given C.V. $(\bar{X})$, say C and solving Eqn. (1) for n. Hence, the general formula is:

$$n = \frac{\sigma^2}{\mu C} \quad . \qquad (2)$$

In practice σ and μ are not known, so they are replaced with preliminary estimates, say S_o and $\bar{X}_o$ obtained with a sample size of n_o. Hence,

$$\tilde{n} = \frac{(S_o)^2}{(\bar{X}_o C)} \qquad (3)$$

In material which follows, formulae are given in terms of parameters with the understanding that these are replaced by estimates in practice.

In order to design a good sampling strategy and to determine optimum sample size, it is required to know what distribution the random variable follows and have preliminary estimates of the parameters.

If the parent distribution is binomial (BD) and one is interested in estimating the parameter P, (proportion of a population) from the number (X) of successes in n trials $(p = \hat{P} = \frac{X}{n})$, it is known that:

$$\sigma^2_{\hat{p}} = \frac{pq}{n} \qquad (4)$$

and $$\text{C.V.}\ (\hat{p}) = \frac{\sigma_{\hat{p}}}{p} = C \qquad (5)$$

Substitute $\sigma_{\hat{p}}$ in (5) from (4) and obtain

$$n = \frac{q}{pC^2} \qquad (6)$$

If the parent distribution is the negative binomial Pielou (1969) has shown that:

$$\sigma^2 = \mu + \frac{\mu^2}{k} \qquad (7)$$

where k is the dispersion parameter of the negative binomial distribution. Substitute σ in Eqn. (2) from Eqn. (7) to obtain

$$n = \frac{\frac{1}{\mu} + \frac{1}{k}}{C^2} \qquad (8)$$

3. PROBALISTIC DEFINITION OF RELIABILITY

If one takes a random sample of size n from a population with mean μ and variance σ^2, then according to the Central Limit Theorem, for a sufficiently large sample size (say, 30 or more), we have the probabilistic statement:

$$P(\bar{X} - z_{\alpha/2} \frac{\sigma}{\sqrt{n}} < \mu < \bar{X} + z_{\alpha/2} \frac{\sigma}{\sqrt{n}}) \simeq (1-\alpha) \qquad (9)$$

where $\bar{X}$ is the sample mean, $(1-\alpha)$ is the confidence coefficient and $z_{\alpha/2}$ is the upper $\alpha/2$ point of the standard normal distribution. We recall that for $(1-\alpha) = .95$, $z_{\alpha/2} = 1.96$ The relation (9) simply says that the confidence interval for

$$\bar{X} \pm z_{\alpha/2} \frac{\sigma}{\sqrt{n}} \qquad (10)$$

will include the mean μ with probability approximately equal to $(1-\alpha)$, regardless of the form of the parent distribution (provided, of course, it has a finite second moment). The greater the n used to obtain $\bar{X}$, the closer the approximation. Moreover, for any fixed n, the level of approximation depends on the particular distribution under consideration.

We now have three quantities; namely, n $(1-\alpha)$, and the length of the interval (10). We simply decide on the value of two of these quantities and solve for the third, say n, which is the optimum sample size. The value of $(1-\alpha)$ is often set at the .95 or .99 levels. The length of the interval (10) can be decided upon in several ways. We will present two of them:

(i) Confidence interval equal to a % of the parameter

The most common and meaningful way to decide upon the length of the interval (10) is to set the half length of it equal to a fixed proportion D of the mean μ, and solve for n.

Hence:

$$z_{\alpha/2} \frac{\sigma}{\sqrt{n}} = D\mu \qquad (11)$$

and thus the general formula:

$$n = \left(\frac{z_{\alpha/2}}{D}\right) \frac{\sigma^2}{\mu^2} \qquad (12)$$

See, for example, Southwood (1978), p. 19.

If the parent distribution is the binomial then (11) becomes

$$z_{\alpha/2}\ \hat{\alpha_p} = D\ p \tag{13}$$

and since

$$\hat{\sigma_p} = \frac{\sqrt{pq}}{n} \tag{14}$$

relation (13) becomes

$$n = \left(\frac{z_{\alpha/2}}{D}\right)^2 \frac{q}{p} \tag{15}$$

If the parent distribution is negative binomial substitute α^2 in Eqn. (12) from Eqn. (7) and obtain

$$n = \frac{z^2_{\sigma/2}\ \left(\frac{1}{\mu} + \frac{1}{k}\right)}{D^2} \tag{16}$$

(b) Confidence interval equal to a fixed positive number

A second way to decide upon the interval (10) is to set half of the length of that interval equal to an arbitrarily chosen positive number h. Thus:

$$z_{\alpha/2}\ \frac{\sigma}{\sqrt{n}} = h \tag{17}$$

Solving for n, we obtain the general formula:

$$n = \left(\frac{z_{\alpha/2}}{h}\right)^2\ \sigma^2 \tag{18}$$

If the parent distribution is binomial, then (11) becomes

$$z_{\alpha/2}\ \hat{\sigma_p} = h \tag{19}$$

and substituting $\hat{\sigma}_p$ in (19) from (14) we have

$$n = \left(\frac{z_{\alpha/2}}{h}\right)^2\ pq \tag{20}$$

The formulae, Eqn. (15) and Eqn. (20) for the binomial are more satisfactory when the differences between p and q are not large.

If the parent distribution is negative binomial, substitute σ^2 in Eqn. (18) from (Eqn. 7) and obtain

$$n = \left(\frac{Z_{\alpha/2}}{h}\right)\ \left(\frac{k\mu + \mu^2}{k}\right) \tag{21}$$

The formulae given above are summarized in Table 1.

4. EXAMPLE OF SAMPLE SIZE DETERMINATION

Based on visual inspection of the fish to heads-on shrimp ratios illustrated in Figure 1, it is clear that they are not randomly or uniformly distributed. Indeed, there is some indication of an L-shaped distribution, suggesting the negative binomial. A negative binomial was fitted to the observed frequencies by a maximum likelihood estimation procedure. Table 2 illustrates the raw data, the expected frequencies and the results of a chi-square goodness-of-fit test. The calculated value of chi-square for 9° of freedom is 13.556. This is less than the 0.95 chi-square value of 16.92. It is therefore apparent that the observed distribution does not deviate significantly from the negative binomial.

Table 1

Some formulae of the required sample size for given precision of estimate

	Reliability defined by: Confidence interval equal to: (a)	(b)	(c)
Parent distribution	Coefficient of variability	Percent of parameter	Fixed positive number
General	$n = \left(\frac{S}{\bar{X}C}\right)^2$	$n = \left(\frac{z_{\alpha/2}}{D}\right)^2 \frac{S^2}{\bar{X}^2}$	$n = \left(\frac{z_{\alpha/2}}{h}\right)^2 S^2$
Binomial	$n = \frac{q}{pC^2}$	$n = \left(\frac{z_{\alpha/2}}{D}\right)^2 \frac{q}{p}$	$n = \left(\frac{z_{\alpha/2}}{h}\right)^2 pq$
Negative Binomial	$n = \frac{\frac{1}{\mu} + \frac{1}{k}}{c^2}$	$n = \frac{\left(Z_{\alpha/2}\right)^2 \frac{1}{\mu} + \frac{1}{k}}{D^2}$	$n = \left(\frac{Z_{\alpha/2}}{h}\right)^2 \left(\frac{k\mu+\mu^2}{k}\right)$

C = coefficient of variability

n = number of samples

S = standard deviation (estimated)

$\bar{X}$ = mean (estimated)

p = probability of success from the number X of successes in n trials $\hat{p} = \frac{x}{n}$

$q = 1 - \hat{p}$

$z_{\alpha/2}$ = the upper $\alpha/2$ percent of the standard normal distribution

The estimated parameters of the negative binomial may now be used for sample size determination based on an observed negative binomial distribution. Assume that one is interested in determining the number of samples of discards required to estimate the ratio within $\pm$ 10 percent of the mean setting $1-\alpha$ at a 95-percent level. In this particular example $\mu = 2.94$, $k = 0.8141$, $D = 0.1$ and $\alpha = 0.05$, so that $Z_{\alpha/2} = 1.96$.

Substituting into the equation in column b of Table 5:

$$n = \frac{Z^2_{\alpha/2}\left(\frac{1}{\mu} r \frac{1}{k}\right)}{D^2} = \frac{1.96\left(\frac{1}{2.94} + \frac{1}{.8141}\right)}{.1^2}$$

Therefore, n = 307.

It is evident that relatively precise estimates of discard ratios will be quite costly in terms of the sampling effort involved. However, it is better to be aware of this problem than to simply assume that the estimates provided by small numbers of samples are precise.

5. EXAMPLE OF SIMPLE RANDOM SAMPLING

Suppose it is desired to estimate the average proportion of the total catch of seine caught whiting discarded by weight from several areas within a given season (quarter). The following data is available by market sampling area:

Table 2

Data of Figure 1 giving fish to shrimp ratios, the parameters of the negative binomial distribution and results of a chi-square test

Ratios	Observed frequency		Expected frequency	Chi-square $(O-E)^2/E$
0.5	75		80.67	0.401
1.5	69		51.44	5.994
2.5	30		36.54	1.170
3.5	20		26.84	1.743
4.5	25		20.04	1.227
5.5	12		15.11	0.641
6.5	10		11.47	0.188
4.5	7		8.74	0.347
8.5	5		6.69	0.425
9.5	6		5.13	0.148
10.5	6		3.94	1.076
11.5	1		3.03	0.197
12.5	4		2.34	computed chi-square, 9 df = 13.556
13.5	2		1.80	
14.5	2		1.40	
15.5	2	15	1.08	
16.5	2		0.84	
17.5	1		0.65	
18.5	0		0.50	
19.5	1		1.74	
	$\bar{X}$ = 2.9393		k = 0.8141	n = 280

Market sampling	Number of vessels landing in each market sampling area
Shetland	450
Buchan	150
Moray Firth	75
Central	75

For each vessel, it is possible to estimate the proportion of the catch discarded by direct observation (sending an observer onboard), and each vessel can be uniquely identified by its registration number. Assume it is desired to estimate the average proportion discarded by weight within $\pm$ 0.10 at the 90-percent confidence level. Note that 0.10 is a fixed positive number, which in this case is the half length of the confidence interval.

From the limited information available, it appears that the sampling distribution of the proportion of the catch which is discarded has a skewed distribution that may be graduated by the negative binomial. From examination of somewhat similar discard data we

have a first estimate of the mean discard rate ($\mu = 0.4$), as well as preliminary estimate of the dispersion parameter ($k = 2$). To obtain the required sample size for simple random sampling, it is possible to substitute these preliminary estimates into the following from Table 5.

$$n = \left(\frac{Z_{\alpha/2}}{h}\right) \quad \left(\frac{k\mu+\mu^2}{k}\right)$$

Where n is the sample size, k and μ are the parameters of the negative binomial as described above, and h is an arbitrarily chosen positive number which is half the length of the confidence interval, and $Z_{\alpha/2}$ is the upper $\alpha/2$ point of the standard normal distribution

In our example $\mu = 0.4$, $k = 2$, $h = 0.1$ and $\alpha = 0.1$. $Z_{\alpha/2} = 1.96$ so that

$$n = \left(\frac{1.96}{.1}\right)^2 \quad \left(\frac{2(0.4) + (0.4)^2}{2}\right) = 184$$

If simple random sampling were applied to the above problem, the sample size under the conditions specified would be 184 vessels, a relatively large number.

6. EXAMPLE OF STRATIFIED SAMPLING

One could expect to do better by stratifying according to the four market sampling areas, since discarding practices are likely to vary by fishing location (area). Using the same sample size as above, and adopting proportional allocation the m_i for the various strata are:

Stratum	m_i	
Shetland	184 (450/750)	= 110
Buchan	184 (150/750)	= 38
Moray Firth	184 (75/750)	= 18
Central	184 (75/750)	= 18
		184

The design may be improved by speculating as to the relative differences in dispersion and sampling costs among the strata by using optional allocation so that:

$$m_i \text{ proportional to } \frac{m_i \sigma_i}{\sqrt{c_i}}$$

where c_i refer to costs.

Suppose sampling costs are twice as high in the Moray Firth and Central areas than in the others, and that preliminary information on dispersion indicates that the relative dispersion is greater (by about 3:2) within the Moray Firth and Central areas as well. The following table lists relative costs, relative dispersions and the allocation that results.

Stratum	Relative cost	Relative dispersion	Estimate of $M_i (\sigma_i/c_i^{1/2})$	m_i
Shetland	1	2	450 $(2/\sqrt{1})$ = 900	184 (900/1293) = 128
Buchan	1	2	150 $(2/\sqrt{1})$ = 75	184 (75/1293) = 11
Moray Firth	2	3	75 $(3/\sqrt{2})$ = 159	184 (159/1293) = 23
Central	2	3	75 $(3/\sqrt{2})$ = 159	184 (159/1293) = 23
			1293	184

Notice that the new allocation is quite different from the prior one. There is a slight increase in the high variance, high cost samples, and a reduction in the number of the low

cost, low variance samples. Sometimes the inclusion of these cost estimates reduces the number of high cost samples. In this case the high cost samples were also the high variance samples.

7. CLUSTER SAMPLING

In cluster sampling the population is divided into groups or clusters, of units. Several of the clusters are chosen at random, and all units in each related cluster become part of the sample. The clusters are often referred to as primaries and the units contained therein are called secondaries.

There appear to be two major reasons that lead to the choice of cluster sampling:

(i) there sometimes is no list of the population available on which to base a sampling frame, and it is felt that such a list would be expensive to obtain, whereas it is relatively easy to obtain a list of clusters of units. For example, if it is desired to sample a particular port for the fishing skippers' estimates of discards, practical procedures would involve sampling clusters of vessel captains - i.e., vessels arriving at the selected port during some specified time interval, and

(ii) cluster sampling may be desirable if the population is such that sampling costs (travel time) may be reduced by selecting adjacent units.

For example, if discard losses for some particular species are being sampled, it may be cheaper to select some ports and sample all vessels in these ports rather than to take a simple random sample of vessels from all ports in the area of interest.

The relative cost for specified precision (and equivalently the relative variance for specified cost) is:

(i) proportional the relative cost of observing one cluster;

(ii) proportional to the variation between clusters, and

(iii) inversely proportional to the relative size of the cluster.

If, in estimating $\bar{X}$ a choice is made between several cluster sizes, it can be shown that the criterion is to choose that cluster size that minimizes the product of sampling variance times total cost (both of which vary, depending upon cluster size).

When cluster sampling is chosen as a matter of convenience, the final estimate will usually be less precise than simple random sampling. Therefore, the decision rests on whether the cost reduction allows the selection of a large enough sample to actually increase precision. Experience by the author on a limited scale suggests that this may not often be the case. This situation contrasts sharply with the stratified sample previously described, where an estimate less precise than that for simple random sampling is highly unlikely. Only in the case where variation <u>within</u> clusters was greater than that between clusters would the estimate be more precise than the simple random case. Such an assessment does not appear likely in sampling for discards. It is therefore, suggested that it is easier to partition the population into groups of homogeneous units (i.e., stratification) than into heterogeneous units as indicated for cluster sampling.

8. REGRESSION ESTIMATOR

The regression estimator is more appropriate than the ratio estimator if the relation between X and W is linear but does not go through the origin. W is an auxiliary variable in this instance. In this case, the estimate of the population mean is:

$$\bar{X}_r = \bar{X} + b\ (\mu_w - \bar{W})$$

where b is an estimate of the change in X when W is increased by 1. The reasoning is that if the sample $\bar{W}$ is below average, one would also expect the sample $\bar{X}$ to also be below average by an amount $b\ (\mu_w - \bar{W})$. The value of b is usually estimated from the sample using the least-squares estimator:

$$b = \frac{\sum_{n} (X_i - \bar{X})\ (W_i - \bar{W})}{\sum_{n} (W_i - \bar{W})^2}$$

Contrary to the case in general regression analysis, it does not appear necesssary to assume exact linearity between X and W, nor that the variance of X for a given W_i is constant, provided that the sample size is large.

As with the ratio estimates, the regression estimate is generally biased. For large samples the ratio of bias to standard error becomes small, making the bias negligible. Furthermore, there is no bias if there exists an exact linear relationship between X and W. What constitutes a "large" sample depends upon how X and W are correlated, and no simple rule of thumb for sample size is evident.

For large samples, the regression estimate is more precise than the simple sample mean provided there is some significant correlation between X and W. The regression estimate is more precise than the ratio estimate unless the relation between X and W is a straight line through the origin. Ratio estimates were emphasized in this report because it is intuitively reasonable to expect the regression between X and W (discards and total catch) to pass through the origin. That is, no discards occur when there is no catch! Indeed, the regression between total catch and discards has been empirically demonstrated to have a W intercept not significantly different from zero in some cases studied. However, the regression estimator is included because it is thought to have utility in the example which follows.

Example of regression estimate: A suggested possible application of the regression estimator in discard estimation is the use of "eyeball" estimates of the auxiliary variable. For example, in the case of discard estimation, suppose that it is desired to estimate discards using the skipper's guesses of discard losses as the auxiliary variable. From the entire fleet in a given area a random sample of vessels would be selected and the exact amount of discards would be determined by the observer. The regression estimator is then applied, labelling the individual rough skipper's estimates W_i, the average of all rough estimates μ_W, and the more thorough estimates X_i.

Suppose the fleet consists of 120 vessels and a sample of 20 is to be drawn. The following analysis might result as shown in Table 3.

The regression estimate of average discards is given by:

$$X_r = \bar{X} + b\ (\mu_w - \bar{W}) = 0.295 + 0.868\ (0.198-0.215)$$

$$X_r = 0.283$$

The variance of this estimate is approximated by:

$$s^2_{\bar{X}_r} \cong \frac{1-f}{n(n-2)} \sum_{n} \left[(X_i - \bar{X}) - b(W_i - \bar{W})\right]^2$$

$$\cong \frac{1 - \frac{20}{120}}{20\ (18)}\ (0.614) = 0.0014$$

Comment: Although the skipper's estimates (W_i) are biased, one might reasonably expect the bias to be fairly constant from one boat captain to the next, except for some random variation. If this "random" variation is not too great, the regression estimator will be nearly unbiased for small samples.

Table 3

Regression estimate example

Population vessel no.	Data W	W_i	X_i	$(X_i-\bar{X})$	$(W_i-\bar{W})$	$[(X_i-\bar{X})(W_i-\bar{W})]^2$	$(W_i-W)^2$	$[(\bar{X}_i-\bar{X})-b(W_i-\bar{W})]^2$
1	0.19	----	----	----	----	----	----	----
2	0.22	0.22	0.30	0	0	0	0	0
3	0.23	0.23	0.27	-0.03	0.01	0.003	0.0001	-0.0387
4	0.15	----	----	----	----	----	----	----
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
119	0.18	0.18	0.25	-0.05	-0.04	0.002	0.0016	-0.0153
120	0.09	----	----	----	----	----	----	----
Totals	23.76	4.30	5.96	0	0	0.0105	0.0121	0.614

$$\mu_W = 23.76/120 = 0.198 \sim 0.20$$

$$\bar{W} = 4.30/20 = 0.215 \sim 0.22$$

$$\bar{X} = 5.96/20 = 0.298 \sim 0.30$$

$$b = \frac{\Sigma(X_i-\bar{X})\ (W_i-\bar{W})}{\Sigma(W_i-\bar{W})^2} = \frac{0.0105}{0.0121} - 0.865$$

APPENDIX 3

The Ratio Estimate

1. BACKGROUND

As the name implies, the ratio estimate technique is concerned with a particular kind of sample estimate, the ratio. In some respects a ratio is similar to a proportion. However, a proportion differs from a ratio in that a ratio has a random variable in both its numerator and denominator, whereas a proportion has a random variable in its numerator and a fixed number in its denominator.

Example - suppose 100 fish are selected to determine the proportion of females. We immediately know that the denominator of the proportion will be 100. The numerator is not known beforehand; it is a random variable. Suppose, however, that a sample of 100 mixed species fish is selected to estimate the ratio of species A to species B. Here, we do not know either the numerator or denominator beforehand, and both are random variables.

In any fishery problem where the ratio estimate is applicable, it is necessary for each item to measure two characteristics, corresponding to the numerator and denominator of the ratio. The estimation of the proportion of fish discarded in shrimp trawling activities by sampling the unsorted catches, is an example of the use of ratio estimation in fishery science.

2. RATIO ESTIMATOR

The estimator

$$\bar{y}_r = \frac{\bar{y}}{\bar{x}} \bar{X} \qquad (22)$$

is the most commonly used estimator of the population mean Y. In $\bar{y}_r$, $\bar{y}$ and $\bar{x}$ are sample means and $\bar{X}$ is the population mean. Since $\bar{X}$ is constant, the variability in y_t comes from the variability in the ratio of sample means, $\bar{y}/\bar{x}$. It is hoped that basing the variability in y_r on $\bar{y}/\bar{x}$ will result in an estimator with a smaller variance than the mean $\bar{y}$ alone.

The ratio estimator is biased except in the case where a regression of y on x is a straight line through the origin of the axes. This assumes the ratio x_i/y_i is approximately constant. The bias is small in large samples.

The sampling distribution of the ratio estimator is complex, since both X and Y vary from sample to sample. However, for large samples, the distribution tends toward normal and the bias in the approximate variance formula becomes negligible.

Inspite of the above-mentioned difficulties, ratio estimation can be extremely useful to the fishery scientist, especially in dealing with the discard problem. If the additional information is easily obtained with a regular sample, the gain in precision is cheap, since only the final computations are affected.

Knowledge of the exact relationship between X and Y is not required, but in order for the precision of the ratio estimator to be greater than a simple sample mean, the following conditions must hold:

$$\rho_{xy} > \frac{CV_x}{2CV_y} \quad , \quad \begin{aligned} CV_x &= \sigma_x/\mu_x \\ CV_y &= \sigma_y/\mu_y \end{aligned}$$

where ρ_{xy} is the product-moment correlation coefficient between X and Y, and CV_x and CV_y are coefficients of variation for X and Y.

The variability of the auxiliary variate, Y, is thus an important factor. If its coefficient of variation is more than twice that of X, the ratio estimate is always less precise, since ρ_{xy} cannot exceed 1. The above result is based on an approximate variance

formula and is applicable to large samples. In fishery discard estimation the variability of the landed catch would usually have a lower rather than a higher coefficient of variation, and precision would be invariably improved with the ratio estimator.

In Figure 3, the estimator $\hat{\bar{y}}_r$ is formed by evaluating the straight line through the origin $y = (\bar{y}/\bar{x})x$ at the known point, $\bar{X}$. It is hoped that the slope of the line $\bar{y}/\bar{x}$, will have a small variance in such applications.

Since the sample data are utilized only in the form of a ratio, the estimator $\bar{y}_r$ is called a ratio estimator. The estimator $\bar{y}_r$, does not estimate a ratio, it estimates the mean $\bar{Y}$, but it does so by means of a ratio.

The sample variance of $\bar{y}_r$ can be calculated approximately by:

$$\text{var } (\hat{\bar{y}}_r) = \frac{1}{n(n-1)} \sum_{i=1}^{n} (y_i - \frac{\bar{y}}{\bar{x}} x_i)^2 \qquad (23)$$

From Equation 3 it is clear that the linear relationship between y and x should pass through the origin. Otherwise the differences $y_i - (\bar{y}/\bar{x})\, x_i$ will be inflated. From Figure 1 the effect of data points not close to the origin can be seen. When the linear relationship describing the (y_i, x_i) points does not pass near the origin the bias in $\bar{y}_r$ is increased, as well as the variance. The bias in $\bar{y}_r$ can be shown to decrease as sample size increases, regardless of whether the relationship passes through the origin or not.

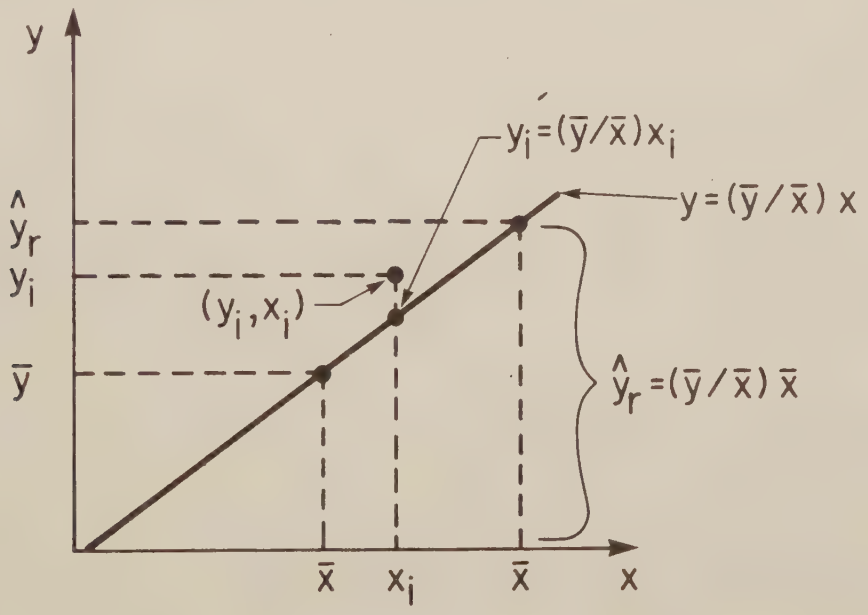

Figure 1 The ratio estimate $\hat{\bar{y}}_r$

APPENDIX 4

The Jackknife Statistic

The jackknife method was originally proposed by Quenouille (Cruz, 1956) as a means for eliminating bias of order n^{-1} from an estimator. No formal derivation of the underlying theory is provided herein. However, it should be noted that the jackknife estimator behaves reliably, both as a means of reducing bias and for providing realistic assessment of error in situations involving ratios.

Durbin (1959) has presented results demonstrating that, for the class of ratio estimators where there existed a linear relationship between the numerator and demoninator, the jackknife statistic both reduced the bias, as well as reducing the variance. A recent application of the jackknife is given for estimating the variance of catch per unit of effort (cpue) by Smith (1980) with an explanation. The following description of the method is provided for purposes of introduction in this report.

An explanation of the jackknife is provided for the case of estimating the value of a single unknown parameter from a random sample of size n. The basis of the jackknife is the reuse of the sample many times by dividing it into subgroups and recombining them to assemble an estimate of the unknown parameter which has good sampling properties and provides an estimate of the variance of this statistic.

Assume a random sample $X_1, X_2, \ldots, X_n$ and that it is desired to estimate the value of an unknown parameter, say θ. Assume also that a reasonable method of estimation is available which provides the estimate $\hat{\theta}$. The jackknife is executed as follows:

Divide the sample into r subgroups (at random if $r < n$) each of size h. The maximum possible number of sub-groups should be used, although $r = n$ (which implies $h = 1$) may not always be feasible.

Remove the first subgroup of data and re-estimate θ from the remaining observations as if they constituted a complete sample of size $n(r-1)$. This provides the first partial estimate of θ_{-1}. Replacing the first subgroup, repeat the estimation procedure after removing the second sub-group to obtain θ_{-2}. Continuing in this manner one gets r partial estimates $\theta_{-1}, \theta_{-2}, \ldots, \theta_{-r}$, the jth being derived from the $h(r-1)$ observations

$$X_1, X_2, \ldots, X_{(j-1)h}, X_{j+1}, \ldots, X_n$$

These partial estimates are then combined with the whole-sample estimate to form r "pseudo-values" by using the formula

$$\hat{\theta}_{*j} = r\hat{\theta} - (r-1)\hat{\theta}_{-j}, \quad j = 1, 2, \ldots, r \tag{24}$$

The average of the pseudo-values is the jackknifed estimate of θ, i.e.:

$$\hat{\theta}_* = \frac{1}{r}\sum_{j=0}^{r} \theta_{*j} = r\hat{\theta} - (r-1)\hat{\theta} \tag{25}$$

where

$$\hat{\theta} = \frac{1}{r}\sum_{j=1}^{r} \hat{\theta}_{-j}$$

This estimate will usually have a smaller bias than the original or "entering" estimate $\tilde{\theta}$, and often will have a smaller variance also.

The estimate of variance derives from the pseudo-value. Tukey conjectured that these may be treated as if they are independently distributed, leading to:

$$S_T^2 = \frac{1}{r(r-1)} \sum_{j=1}^{r} (\hat{\theta}_{*j} - \hat{\theta}_*)^2 \qquad (26)$$

$$= \frac{r-1}{r} \left[\left(\sum_{j=1}^{r} \hat{\theta}_{-j}^{\,2} \right) - r\hat{\theta}^2 \right]$$

as an estimate of var $(\hat{\theta})$ or var $(\hat{\theta}_*)$.

If we assume that:

$$t_T = (\hat{\theta}_* - \theta) \; / \; S_T$$

has a central student's t distribution on (r-1) degrees of freedom, then this can be used to perform tests and to set 100 (1-α) percent confidence intervals for θ of the form $(\hat{\theta}_* - t \cdot S_T, \; \theta_* + t \cdot S_T)$ where t is the 100 (1-α/2) percent point of the t_{r-1}, distribution.

The above concepts can be formalized to two or more parameters. These will not be considered here, but reference is made to (Sukhatme and Sukhatme, 1970) for the interested reader.

1. EXAMPLE OF JACKKNIFE METHOD

Table 1 illustrates the use of the jackknife estimator. The data (in terms of percent of total catch discarded) is taken from Table 3 of this report, and the geometric mean of these percentages was used for estimating global finfish discards. In this instance (Table 1) the calculations for the jackknife statistic are provided in sufficient detail so that they can be repeated by interested users. It is evident from this table that the confidence limits derived from this estimation procedure are fairly small, when the variability of the original data is taken into consideration.

Table 1

Original data, mean and jackknife variance estimate of the percentage of discards from finfish fisheries listed in Table 3 of this report

	Percent Discarded		Percent Discarded
(1)	6	(9)	84
(2)	26	(10)	31
(3)	5	(11)	24
(4)	100	(12)	9
(5)	28	(13)	20
(6)	13	(14)	19
(7)	18	(15)	0.8
(8)	21		

Grand mean = 26.99 = r , Geometric mean (GM) = 16.50

r_{-1} = 28.48				
r_{-2} = 27.06	r_{-10} = 26.70	r_1 = 15 (26.99) - 14 (28.48) = 6.03	$\bar{r}$ = 27.04	
r_{-3} = 28.56	r_{-11} = 27.20	r_2 = 25.96	r_{10} = 31.00	s^2 = 793.02
r_{-4} = 21.77	r_{-12} = 28.27	r_3 = 4.96	r_{11} = 24.00	$s_{\bar{x}}$ = 7.27
r_{-5} = 26.91	r_{-13} = 27.49	r_4 = 100.86	r_{12} = 9.02	
r_{-6} = 27.99	r_{-14} = 27.56	r_5 = 28.06	r_{13} = 19.94	
r_{-7} = 27.63	r_{-15} = 28.86	r_6 = 12.94	r_{14} = 18.96	
r_{-8} = 27.41		r_7 = 17.98	r_{15} = 0.76	
r_{-9} = 22.91		r_8 = 21.06		
		r_9 = 84.06	95 percent confidence limits: $\bar{r}$ = 12.45 < 27.04 < 41.53	

APPENDIX 5

Krumbein and Tukey Analysis of Variance

1. BACKGROUND

A statistical technique which is relatively poorly known to fisheries investigators (Krumbein and Tukey, 1956) seems very well suited for detecting heterogeneity of percentage composition in a multi-stage sampling design. It has been utilized by Briggs and O'Connor (1971) to compare shore-zone fishes over different substrates and was suggested by Saila (1980) as a means for assessing environmental impacts.

The purpose of this section is to briefly describe and illustrate the use of this statistical method to detect changes in the species composition of fisheries which capture several species. More specifically we are interested in detecting, in a statistical sense, a change in the species composition of the gross landings from several defined areas. For example, we might be interested in comparing the species composition in two geographically similar areas - one of which is fished by trawls with some type of gear designed to minimize losses of non-target species with another area fished with conventional gear or we might be interested in temporal changes in catch compositions. The material which follows is slightly modified, for the purpose of this study, from Saila (1980) who outlined a simplified version of the original Krumbein and Tukey (1956) model. This original model was derived for the simultaneous evaluation of a number of mineral or chemical constituents in rock samples. The simultaneous evaluation is accomplished for certain studies involving spatial or temporal variability by expressing several response variables as proportions or percentages, when the total adds up to 100 percent.

2. MODEL AND ANALYSIS

In order to apply statistical techniques to any experimental design and analysis, it is necessary to have a clear and precise description of the experiment which identifies the measurements and the design parameters available, as well as potential sources of uncertainty and error. Such a description is provided by a model which explicitly relates the observations of interest (dependent variables) to various factors (independent variables) and error sources. An example of a practical experimental model is provided by the following equation, which decomposes a single observation (X_{ikm}) into several parts:

$$X_{ikm} = \mu + A_i + S_{ik} + T_m + AT_{im} + ST_{ikm} \qquad (27)$$

where

X_{ikm} = observation at area i, sample k and type species m

μ = mean of all observations

A_i = effect of the i^{th} area thought to influence X_{ikm}

S_{ik} = effect of the k^{th} sample in area i thought to influence X_{ikm}

T_m = effect of the m^{th} type species thought to influence X_{ikm}

AT_{im} = first order interaction term between areas and type species

ST_{ikm} = first order interaction term between samples from each area and type species within each sample

The term type species is used because it may be desirable to group true species by morphologically similar groups in some cases or by some ecological groups or lumped (aggregated) species into broader taxonomic groupings. The index j is omitted in this example to permit easier comparison with the original model of Krumbein and Tukey.

The analysis of variance table specified by equation (1) is partitioned as follows:

Source of Variation	Degrees of Freedom		
A_i	i - 1	$\sigma^2_w + n_t\sigma^2_{S:A} + n_s n_t \sigma^2_A$	*
S_{ik}	i (k-1)	$\sigma^2_w + n_t\sigma^2_{S:A}$	*
T_m	m - 1	$\sigma^2_w + n_a n_s \sigma^2_T$	*
AT_{im}	(i-1) (m-1)	$\sigma^2_w + n_s\sigma^2_{AT}$	*
ST_{ikm}	i(k-1) (m-1)	σ^2_w	*

* not tested

where n_a = number of areas, n_t = number of species, and n_s = number of samples from each area.

In the context of an actual experiment, the observation X_{ikm} would represent the arc sine transformed count (percentage of individuals per unit area) of the m^{th} species in the k^{th} sample located in area i. If we consider a specific experiment, say with two similar areas (one of which has been fished with special savings gear and the other which is fish conventionally) with three samples from each area and with five types of species to be compared, then the total degrees of freedom for this experiment is (2 x 3 x 5) - 1 = 29. The total degrees of freedom can be partitioned according to the degrees of freedom column of the analysis of variance table given above as $A_i = 1$, $S_{ik} = 4$, $T_m = 4$, $AT_{im} = 4$ and $ST_{ikm} = 16$. This sum results in the 29 degrees of freedom indicated.

In this type of analysis, the mean squares for main effects are of no interest, and the justification for not testing them is given by Krumbein and Tukey (1956). Only the interaction mean squares between species and sampling levels are of interest here. In the above-mentioned model interaction, mean squares are calculated for areas X types of species and replicate samples within areas X types of species interactions. Using these mean square values the F ratio (variance ratio) of area X species types to replicate X species types can be used to test the hypothesis that variability in species composition between areas (savings gear versus conventional trawls) is not significantly greater than that within replicates at each areas. Because temporal variability among biota is often found, it is assumed that the replicates and area comparisons are made at nearly the same time.

The arrangement of the data for analysis is shown in Figure 1 using the specific example previously cited. The items in each column are first added to obtain the summation over m. The dots in Figure 1 always represent summation over the index. These summations are next combined over replicates (1 + 2 + 3) to obtain the summation over km, and these are finally combined over gears (A and B) to obtain the summation over ikm. A second condensed table is prepared by adding replicates (1 + 2 + 3) for each type species, to obtain a summation by type species, and these are combined by gears to obtain the summation over ik. By carrying the totals to the right, the summation over ikm is obtained.

The manner of computing the raw sums of squares is shown in the bottom of Figure 4. As indicated, all the original items and all the sums are squared to obtain the six numbers designated as I to III and A to C. These numbers are then used in the analysis of variance shown in Figure 2. The final sums of squares are obtained by making the subtractions indicated in the second column of Figure 6. The degrees of freedom are distributed as shown in the third column.

In conducting the analysis the first three mean squares are not used. The F test is made by taking the ratio of the last two mean squares in the last column (i.e., gears X types divided by samples within gear X types). The observed variance ratio is used to test the following hypothesis: The variation in over-all species composition between gear types (savings versus conventional) is not significantly greater than the variation in species composition between samples in a given area.

An extension to the model described herein (from a two-level to a three-level nested sampling plan) is given by Krumbein and Tukey (1956). Further extensions to include additional factors are also possible, but are not considered herein.

3. EXAMPLE

The following numerical example is provided to give the interested reader further insight into its application. Table 1 illustrates the percentage composition of certain families of fishes by weight in monthly shrimp trawl samples during the years 1974-75. These data were gathered off the coast of South Carolina, USA. Table 1 illustrates similar data for an earlier period (1931-35) taken from the same region. It is interesting to compare these two periods and to determine whether there have been significant differences in the fish species composition between these two sampling periods. These data lend themselves well to the Krumbein-Tukey method. Prior to analysis these data were transformed by the arc sine percentage transformation. The transformed data are illustrated in Tables 2a and 3b.

The results of the analysis (Tables 3a and 3b) indicate that there were significant differences in the species composition of the discarded catches between the two sampling periods. This is an interesting finding and suggests that careful monitoring of shrimp by-catch discards in conjunction with analyses of catches from directed fisheries are needed for proper management.

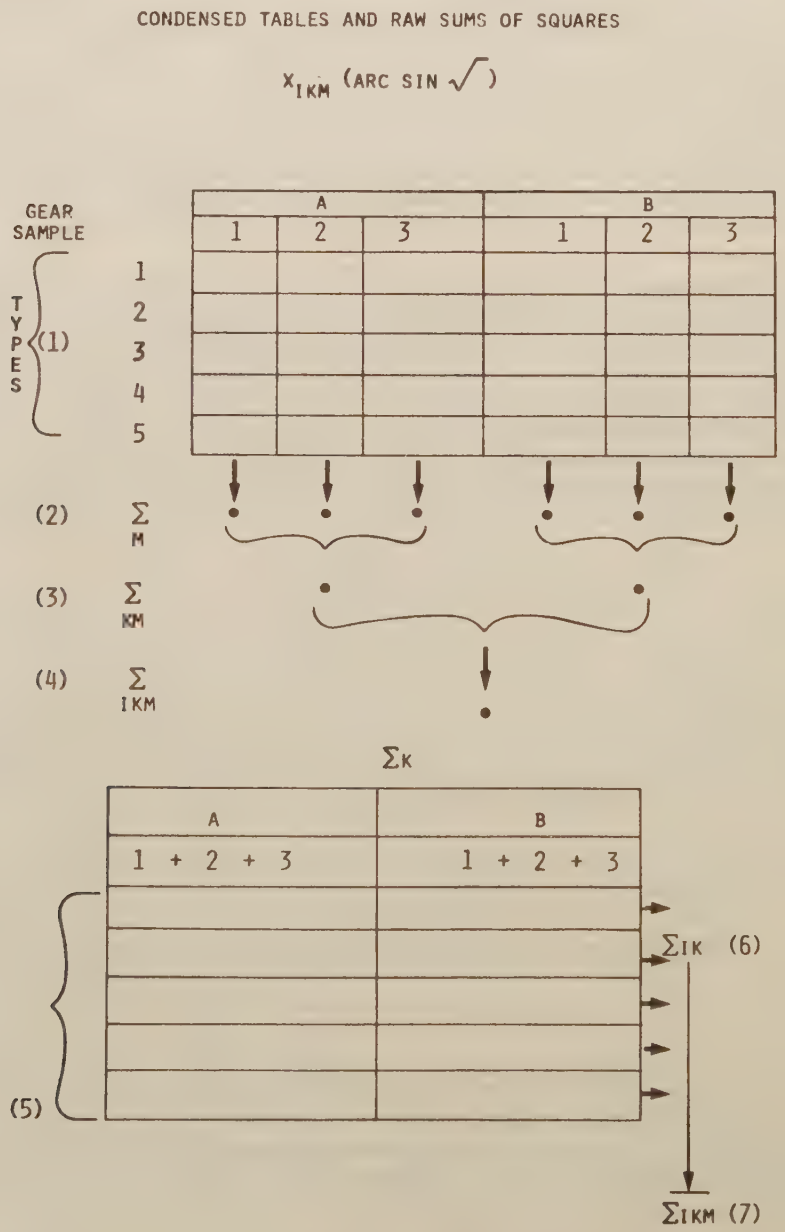

Figure 1 (continued)

III: $\sum_{IK} (\sum_{M} x_{IKM})^2 / M$ SUM OF SQUARES OF ALL ITEMS (2), DIVIDED BY M.	C: $\sum_{IKM} (x_{IKM})^2$ SUM OF SQUARES OF ALL ITEMS IN (1).
II: $\sum_{I} (\sum_{KM} x_{IKM})^2 / KM$ SUM OF SQUARES OF ALL ITEMS (3), DIVIDED BY KM.	B: $\sum_{IM} (\sum_{K} x_{IKM})^2 / K$ SUM OF SQUARES OF ALL ITEMS IN (5) DIVIDED BY K.
I: $(\sum_{IKM} x_{IKM})^2 / IKM$ SQUARE OF GRAND TOTAL (7) DIVIDED BY N = IKM.	A: $\sum_{M} (\sum_{IK} x_{IKM})^2 / IK$ SUM OF SQUARES OF ALL ITEMS (6) DIVIDED BY IK.

Figure 1 Schematic diagram for condensation of data and computation of mean squares for the multivariate model. The case illustrated is for two gear types, three samples per area and five species types described in the text. The dots in the figure refer to sums over their respective indexes

ANALYSIS OF VARIANCE

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	
BETWEEN GEARS	II - I = SS_1	I - 1	SS_1 / I-1	NOT USED
BETWEEN SAMPLES WITHIN GEARS	III - II = SS_2	I (K-1)	SS_2 / I (K-1)	
BETWEEN TYPES (SPECIES)	A - I = SS_3	M - 1	SS_3 / (M-1)	
GEARS X TYPES	I + B - (II + A) = SS_4	(I-1) (M-1)	SS_4 / (I-1) (M-1)	
SAMPLES WITHIN GEARS X TYPES	(II + C) - (III + B) = SS_5	I (K-1) (M-1)	SS_5 / I (K-1) (M-1)	

Figure 2 Form of multivariate analysis of variance table for the two-way nested design example. Compare with Figure 1 for the subtractions indicated in the second column.

Table 1a

Percent contribution by families to monthly shrimp trawl samples.

(From Table 2, Keiser, 1979) Data for 1974-75.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Sciaenidae	22.6	68.6	45.5	36.7	45.5	77.8	71.0	62.3	50.6	51.2	45.5	50.4
Engraulidae	19.7	10.2	4.3	3.8	5.6	6.3	10.4	9.9	17.0	21.1	21.7	16.4
Clupeidae	40.2	4.4	15.1	2.2	20.9	6.2	5.2	8.2	3.4	5.5	16.4	10.8
Gadidae	4.3	5.2	21.5	36.9	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Others	13.2	11.6	13.6	20.4	14.1	9.7	13.4	19.6	30.0	22.6	16.4	22.4

Table 1b

Percent contribution by families to monthly shrimp trawl samples.

(From Table 11, Anderson, 1968) Data for 1931-35.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Sciaenidae	86.8	74.5	29.0	42.2	61.8	63.3	88.5	87.6	90.2	85.7	91.1	94.7
Engraulidae	0.6	3.7	16.6	2.5	16.1	11.2	0.6	0.7	0.0	1.6	2.5	1.6
Clupeidae	9.3	14.3	8.1	1.7	7.9	9.7	0.3	0.1	0.0	0.1	0.1	0.1
Gadidae	0.1	3.7	32.6	37.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
All Others	3.2	3.8	13.7	16.1	14.1	15.7	10.6	11.6	9.8	12.6	6.3	3.6

Table 2a

Arc sine$\sqrt{\text{percentage}}$ transformation of data of Table a.

1974-75 data.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Sciaenidae	28.4	55.9	42.4	37.3	42.4	61.9	57.4	52.1	45.3	45.7	42.4	45.2
Engraulidae	26.4	18.6	12.0	11.2	13.7	14.5	18.8	18.3	24.4	27.4	27.8	23.9
Clupeidae	39.4	12.1	22.9	8.5	27.2	14.4	13.2	16.6	10.6	13.1	23.9	19.2
Gadidae	12.0	13.2	27.6	37.4	21.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Others	21.3	19.9	21.6	26.8	22.1	18.2	21.5	33.2	33.2	28.4	23.9	28.2

Table 2b

Arc sine$\sqrt{\text{percentage}}$ transformation of data of Table b.

1931-35 data.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Sciaenidae	68.7	59.7	32.6	40.5	51.8	52.7	70.2	69.4	71.8	67.8	72.6	76.7
Engraulidae	1.4	11.1	24.0	9.1	23.7	19.6	1.4	1.5	0.0	7.3	9.1	7.3
Clupeidae	17.8	22.2	16.5	7.5	16.3	18.2	1.0	0.6	0.0	0.6	0.6	0.6
Gadidae	0.6	11.1	34.8	37.8	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0
All Others	10.3	11.2	21.7	23.7	22.1	23.3	19.0	19.9	18.2	20.8	14.5	10.9

Table 3a

Preliminary computations for analysis of discarded fish by families from shrimp trawls. Refer to Figure 2 for model data analysis. M = 5, K = 12, I = 2

III	$\frac{302824.3}{5} = 60564.86$	$C = 105065.61$
II	$\frac{3605802.02}{60} = 60096.7003$	$B = \frac{1133192.19}{12} = 94432.6825$
I	$\frac{7181328.04}{120} = 59844.4003$	$A = \frac{2198147.030}{24} = 91589.4596$

Table 3b

Multivariate analysis of variance table for the two-way nested design

Source	Sum of squares	Degrees of freedom	Mean square
Between periods	252.30	1	252.30
Between months within areas	486.1597	11	42.56
Between species	31745.0593	4	7936.26
Periods x species	2590.9229	4	647.73
Months within periods x species	10632.9275	49	241.86

$F = 2.68$

$F_{.05}$ for df = 4,44 = 2.60

APPENDIX 6

Discard Assessment of Commercial Species when Total Weight of Discards is Unknown Hillis's Method

Much of the material which follows has been freely adapted from reports presented by Hillis (1981, 1981a) who developed the technique to be described.

1. BACKGROUND

The method consists of calculating quantities of discards from sample length frequencies of fish caught, fish landed and fish discarded. The method relies on data over the great majority of the length-range of the catch and provides an estimate of the numbers and weight of discards corresponding to a given weight of catch.

The applications of the method include: (a) a check on other on-the-spot estimates; (b) when the volume of the discards is too great to permit weighing or when discarding is being done during the sorting operations, and (c) when vessels return to port with unsorted catch. Hillis notes that in the latter case a potential source of bias must be recognized if a portion of the catch is brought in which may not be representative of the whole catch.

Obviously, the method is applicable only on a single species basis and only when there is some size for that species below which it is thrown overboard.

2. BASIS OF METHOD

A factor is determined by which the size-frequency sample of discards can be adjusted so that after logarithmic transformation the shape of the size-frequency sample of discards plus landings will, as nearly as possible, match that of the catch. The presumed advantage of logarithms is to adjust for different sample sizes. A consistent difference in values (X), within length groups between the two distributions is sought. Let:

$$X = \log (L + (D \times F) / C)$$

$$= \log (L + (D \times F) - \log C)$$

where C = number of fish in catch sample
L = number of fish in landings sample
D = number of fish in discards sample

and F is a variale scale factor used as a multiplier for D to get X as nearly constant as possible over the relevant length range.

A computer program written in BASIC language has been provided by Hillis (1981) which calculates the mean value of X over a selected length range, weighted by (non-transformed) numbers of C per length group and excluding extreme values to avoid erratic and zero values, using a sample of F to seek the F value for which the standard deviation of $\bar{X}$ (the standard error of the mean) has its lowest value. This value of F is taken as the optimum. The optimum is defined as that value for which the combined length-frequency of landings plus adjusted discards (L +(D x F)) most closely resemble that of the catch C. The size of the minimum standard deviation depends on the quality of the data. Clearly this method is adaptable for hand calculation as well, although it can become tedious.

APPENDIX 7

A Suggested Methodology for Monitoring Discard Practices

1. INTRODUCTION

Recently Stearns (1981) evaluated the precision and power of significance tests for four measures of non-metric time series. These measures were Colwell's (1974) C and M and Goodman and Kruskal's λ_{RIC} and τ_{RIC}. It is suggested that these may have considerable utility in the analysis of data sets smaller than those traditionally exposed to time-series analysis. The situation of attempting to detect changes in fish to shrimp by-catch ratios is an example of such a problem.

2. BACKGROUND AND EXAMPLE

A time series of quarterly fish to shrimp weight ratios is provided in Table 3a in Appendix 5. These data are similar to those reported by Keiser (1977) but have been extended to provide a longer series than that provided by the author. The first step in analysis involves casting the data into a frequency matrix. That is, one must decide upon the number of states (rows, corresponding to fish: shrimp weight ratios in this case) and how many times (columns, corresponding to time intervals) there are to be in the matrix. In this case it was relatively straightforward to group the data into unit weight ratio increments between 1 and 6 and to seek annual fluctuations, because they have been observed or reported previously. These decisions imply transformations (part b of Table 1) and development of a frequency matrix (part c of Table 1). In this frequency matrix, the largest number that can occur is 3 because we have divided the total data into three annual periods of four quarters each.

τ_{RIC} measures the proportion of variation in row categories explained by column categories.

3. CALCULATION AND EXAMPLE

It has been suggested (Stearns, 1981) to use Colwell's measures first to locate the most revealing ways to categorize the data, and then to calculate $\hat{\lambda}_{RIC}$ and $\hat{\tau}_{RIC}$ for further insight in interpretation.

In the example of shrimp: fish discard ratios given in Table 3a in Appendix 5, the following values were calculated: H(X) = 1.3863, H(Y) = 1.4241, H(XY) = 1.8081. C = 0.1260, M = 0.6228, P = 0.7488, $\hat{\lambda}_{RIC}$ = 0.7857 and $\hat{\tau}_{RIC}$ = 0.2727.

From these data it is clear that constancy (C) is low indicating changes in fish: shrimp ratios. M is relatively high indicating that there are indeed strong periodic (quarterly in this case) fluctuations in the fish: shrimp ratios. With respect to $\hat{\lambda}_{RIC}$, it appears that it is possible to reduce the error in predicting the state of the fish: shrimp ratio by about 79 percent, relative to predicting only from a knowledge of how frequently different fish: shrimp ratio states occur, if we know the quarter in which the ratio was taken. In addition, about 27 percent of the variation in fish: shrimp ratios can be explained by the period (quarter) in which the ratio was estimated.

These four measures complement each other and the major inferences which can be made indicate that there has indeed been some change in fish: shrimp ratios over the sampling period in question. This is primarily due to the low value for constancy (C).

Table 1

Average seasonal (quarterly) fish/shrimp ratios observed on commercial vessels off South Carolina, USA, 1974-76. Hypothetical data based on a limited actual data set.

RAW DATA (a)

	1974								1976			
Quarter	1	2	3	4	5	6	7	8	9	10	11	12
F/S ratio	4.86	2.17	1.19	1.76	5.24	2.80	1.34	1.96	5.39	3.11	1.70	2.42

TRANSFORMED DATA (b)

(4 seasons, 5 states)

Quarter	1	2	3	4	1	2	3	4	1	2	3	4
State	4	2	1	1	5	2	1	1	5	5	1	2

FREQUENCY MATRIX (c)

		Seasons (t)				
		1	2	3	4	Y_i
	1			3	2	5
	2		2		1	3
States (s)	3		1			1
	4	1				1
	5	2				2
X_i		3	3	3	3	12 = Z
		1	2	3	4	5
State		1-1.99	2-2.99	3-3.99	4-4.99	5-5.99

Colwell's (1974) measures are as follows:

s = no. of states.

t = no. of times

X_i = column totals = $\sum_{i=1}^{s} N_{ij}$

Y_i = row totals = $\sum_{j=1}^{t} N_{ij}$ and

Z = the grand total = $\sum_i \sum_j N_{ij}$

$= \sum_j x_j = \sum_i y_i$.

Uncertainty with respect to time is:

$$H(X) = - \sum_{j=1}^{t} (X_j/Z) \log_e (X_j/Z).$$

Uncertainty with respect to state is:

$$H(Y) = - \sum_{i=1}^{s} (Y_i/Z) \log_e (Y_i/Z) .$$

Uncertainty with respect to the interaction of time and state is:

$$H(XY) = - \sum_{i} \sum_{j} (N_{ij}/Z) \log_e (N_{ij}/Z)$$

From these one can define:

$$\text{Constancy} = C = 1 - H(Y) / \log_e s$$

$$\text{Contingency} = M = \{H(X) + H(Y) - H(XY)\} / \log_e s$$

$$\text{Predictability} = P = C + M$$

$$= 1 - \{H(XY) - H(X)\} \log_e s.$$

Goodman and Kruskal's measures are:

$$\lambda_{RIC} = \frac{\sum_{j=1}^{t} \text{colmax}_j - \text{rowsumax}}{Z - \text{rowsumax}}$$

$$\tau_{RIC} = \frac{\sum_j \sum_i \frac{1}{x_j} N_{ij} - \frac{1}{Z} \sum_i Y_i}{Z - \frac{1}{Z} \sum_i y_i}$$

where: colmax = the largest value in column j,

rowsumax = the largest row sum

and X_j, Y_i, N_i, and Z are as defined previously.

4. INTERPRETATION OF MEASURES

Contingency (M) measures strong predictable fluctuations, and it will be large if the column dimension of the frequency matrix matches the natural periodicity of the phenomenon.

Constancy (C) will be large for an unchanging measure, regardless of the dimensions of the matrix.

Predictability (P) is the sum of C + M.

All three above measures range between zero and one in magnitude. Clearly C and M are not independent, because their sum ≤ 1.

λ_{RIC} measures the proportional reduction in error gained by predicting the row category given knowledge of the column category, relative to predicting the row category under the assumption of statistical independence of rows and columns.

APPENDIX 8

Estimators

The material in this Appendix attempts to bring together some of the estimators of means and variances, as well as formulae for determining sample allocation. Clearly, this is not a comprehensive review of estimators, and it deals only with designs suggested in the body of this report.

Stratified sampling:

The population mean is estimated by $\bar{X}_{st}$, the weighted average of the stratum means:

$$\bar{X}_{st} = \frac{1}{M} \sum_i M_i \bar{X}_i, \quad M = \sum_i M_i$$

where N = number of strata, M_i = sub-population size of i^{th} stratum, $\bar{X}_i$ = sample mean from i^{th} stratum.

The estimate of sampling variance of $\bar{X}_{st}$ is also a weighted average:

$$S^2_{\bar{X}_{st}} \sum_i \left(\frac{Mi}{M}\right)^2 S^2_{\bar{X}_i}$$

where $S^2_{\bar{X}_i}$ = sampling variance from the i^{th} stratum

$$= (1-f_i) \frac{\sum_i^{m_i} (X_{ij} - \bar{X}_i)^2}{m_i (m_i - 1)} , \quad f_i = \frac{m_i}{M_i} ,$$

and m_i = sample size from the i^{th} stratum.

The total sample may be divided up among strata according to the proportional allocation scheme:

$$m_i \propto M_i .$$

If estimates are available for the variances within each stratum (σ^2_i) and the costs of sampling from each stratum (c_i), optimal allocation may be used:

$$m_i \propto \frac{M_i \sigma^2_i}{\sqrt{c_i}}$$

Ratio estimator:

The ratio estimate of the population mean of the X is given by:

$$\bar{X}_R = \left(\{ \frac{\sum_{i=s}^{n} X_i}{\sum_{i=s}^{n} y_i} \} \right) \mu_y = \frac{\bar{X}}{\bar{y}} \mu_y$$

For large sample sizes, the approximate sampling variance is estimated by:

$$s^2_{\bar{X}_r} = \frac{1-f}{n} \{ \frac{\sum_i^n (X_i - \frac{\bar{X}}{\bar{Y}} Y_i)^2}{n-1} \}$$

For smaller sample sizes the jackknife method of estimating variances previously outlined in detail is suggested.

Regression estimator:

The regression estimate of the population mean of the X variable is given by:

$$\bar{X}_r = \bar{X} + b\ (\mu_y - \bar{Y})$$

The least squares estimator for b is:

$$b = \frac{\sum_{i}^{n} (X_i-\bar{X})\ (Y_i-\bar{Y})}{\sum_{n} (Y_i-\bar{Y})^2}$$

The sampling variance for large samples is estimated by:

$$s^2_{\bar{X}_r} = \frac{1-f}{n(n-2)} \sum_{i}^{n} \{(X_i-\bar{X}) - b(Y_i-\bar{Y})\}^2 .$$

APPENDIX 9

Summary of By-Catch by Regions for Shrimp and Finned Fisheries

Some indication of the regional magnitude and nature of the by-catch is given in material which follows.

Arabian Gulf Region Mixed Fishery:

Grantham (1980) has reported on the by-catch from fisheries in the Arabian Gulf region. Much of this information is summarized in Table 1 and Table 2 showing the total by-catch by member countries in Table 1 and the species abundance in the by-catch in Table 2. Grantham has suggested that at least one-half of the commercial by-catch of 32 000 t during 1979 was discarded at sea.

Table 1

(from Grantham, 1980)

By-catch and food fish landings by member countries in 1979
Estimated, liveweight (t)

	Artisanal by-catch	Commercial by-catch	Total by-catch	Food fish and shrimp landings
Qatar	180	130	310	1 400
Bahrain	160	1 400	1 560	4 720
Oman	800	1 000	1 800	26 000
UAE	1 100	500	1 600	16 500
Saudi Arabia	300	0	300	6 000
Kuwait	220	3 000	3 200	9 800
Iraq	500	8 000 a/	8 500	50 700
Iran b/	1 200	18 000	19 200	39 900
Total	4 460	32 030	36 470	155 020

a/ Mainly outside project area

b/ Includes catches outside project area; statistics for 1977

Gulf of California

Shrimp fishery - About 120 000 t of by-catch have been reported to have been caught each year by trawlers based at the ports of Puerto Penasio, Mazatlan and Guaymas (Green, 1981). Studies by Perez Mallado (1982) indicate:

(i) a mean shrimp by-catch ratio of 1:9.8;

(ii) an average by-catch yield of 90 kg/h;

(iii) yields of by-catch are greater during warm seasons than during cold seasons;

(iv) approximately 105 species of fishes from 52 families observed. Of these, nine species or groups of closely related species constitute 65 percent of all fish examined;

(v) demersal fish predominate in the by-catch;

(vi) the majority of by-catch species range from 8 to 14 cm in length, and

Table 2

Species abundant in gulf by-catch
(from Grantham, 1980)

			Qatar	Bahrain [a/]	Oman	UAE	Saudi Arabia	Kuwait [a/]
Catfish	*Arius thalassinus*	b/	++		++		++	
Triggerfish	*Abalistes* spp.		++	10			++	
Flounders	Bothidae	b/	+	+		++	++	
Small trevallies	Carangidae	c/	++	3	+	+		6
Wrasses	*Choerodon* spp.		+	+			++	
Whitefin wolf herring	*Chirocentrus nudus*					++	+	
Parrotfish	*Collydon* sp.	c/	+		++	+		
Dolphinfish	*Coryphaena hippurus*						++	
Eastern little tuna	*Euthynnus affinis*	b/	++					
Mojaras	*Gerres* spp.			34				1
Greyfin jewfish	*Johnius aneus*							2
Ponyfish	Leiognathidae		++	2	+			20
Small emperors	*Lethrinus* spp.	c/	++	10	++			
Red snapper	*Lutjanus* spp.	b/	++	++				
Moray eels	Muraenesocidae		+		++			
Dogfish	*Mustelus canis*	b/			++			
Gizzard shad	*Nematalosa nasus*					++	++	
Sand perches	*Parapercis* spp.						++	
	Pellona ditchella							3
Stripped sea catfish	*Plotosus anguilaris*				++			
Blocked grunt	*Pomadasys multimaculatus*				++			
Indian halibut	*Psettodes erumei*	b/	+		+		++	
Tripod fish	*Pseudotriacanthus* sp.							5
Sardinella	*Sardinella* spp.	b/	++					
Monacle bream	*Scolopsis* spp.			+		+	++	
Small rabbitfish	*Siganus* spp.	c/	++			+		
Red mullet	Surmullidae	b/	++					
Lizardfish	Synodontidae		++	2	++		+	
Pufferfish	Tetraodontidae	b/	+	5	+		+	+
Moustached anchovy	*Thryssa mystax*							3
Goatfish	*Upeneus* and *Mulloidycythys* spp.	b/	++	14				12
Sharks and rays	Elasmobranch	b/	++	++	++	++	++	42

Notes: Only those species known to occur are listed here and in the country reports. The lists are not complete, and the absence of an entry for a particular species does not necessarily imply that it does not occur in the by-catch of that particular country.

++ = Very common or abundant
+ = Occurs occasionally or in small quantity.

a/ The figures given for Bahrain and Kuwait are the weight percentages of species in the by-catch from a limited number of trawls

b/ Species commanding a significant market value outside the region

c/ Species with some market value elsewhere within the region.

(vii) a toxic species (the bullseye puffer, Sphoeroides annulatus occurs in the by-catch in small quantities.

Young and Romero (1977) list species and species groups and other data from the Central Gulf of California (Table 3).

Southeastern USA and Gulf of Mexico

Shrimp fishery - Pellegrin (1982) has reviewed the fish discards from the southeastern United States shrimp fishery. Tables 4 and 5 from Pellegrin's review adequately summarize the magnitude of the by-catch and the species composition for both the Gulf and South Atlantic regions.

Thailand

Mixed fishery - Saisithi (1982) has reported that more than 40 percent of the marine yield consisted of by-catch in the past five years. Table 6 and Table 7 from Saisithi's report summarize the yields of marine organisms, the by-catch, as well as the by-catch component consisting of small pelagic fish. It is clear from Tables 6 and 7 that virtually all of the by-catch is presently used for fish meal production, but that there is some possibility of utilizing small pelagic fish more efficiently.

WECAF Region

Shrimp fishery - Caddy (1982) calculated the estimated weight of discards for this region as about 425 000 t. This was based on a mean shrimp: by-catch ratio of 1:8.04 and overall landings of shrimp of 176 000 t from this region. Jones and Villegas provide a somewhat more comprehensive estimate of about 200 000 t.

Sri Lanka

Shrimp fishery - Subasinghe (1982) has estimated that about 30 000 t of small fish are estimated to be caught annually as by-catch from shrimp trawling. The family Leiognathidae forms over 80 percent of this by-catch. Table 8 presents the best available estimates of the size of the shrimp by-catch in Sri Lanka, and the quantities discarded. The two areas mentioned account for 60 percent of the shrimp production of this country.

Summary of Shrimp Fishery Estimated By-Catch

Allsopp (1980) has provided a summary table (Table 9) of the catches of shrimp and prawns by FAO statistical zones and has multiplied the reported landings by factors to provide an estimate of the approximate fish by-catch from global shrimp fisheries. Allsopp (Table 9) refers to the total by-catch and not to the discarded gross landings. Therefore, it is considerably higher than the estimates provided in the body of this report.

Fin Fisheries - Northwest Atlantic Area

Mayo et al., (1981) have described a simulation technique for estimating discards from commercial otter trawls and have provided an estimated discard rate of 43 percent of the total weight retained by the meshes. It was suggested that the dominance of spiny dogfish Squalus acanthias accounted for much of the high discard rates obtained in this study. Spiny dogfish are not retained by US vessels fishing off the northeast coast of the USA. In Table 10, Mayo et al., indicate the magnitude of this discard rate. It is interesting to note that the figure does not change appreciably with increased mesh sizes. This value is somewhat higher than that calculated in the body of the report, and the explanation provided seems reasonable.

Fin Fisheries - Northeast Atlantic Area

Jermyn and Robb (1981) have summarized data on discard rates of three important demersal species on the Northeast Atlantic region. In Table 11 they compare discard rates by seine and trawl for the three species over a five-year period. It is clear that these data provide lower discard values than those suggested by Mayo et al. (1981). However, the two data sets are not comparable because the data of Jermyn and Robb refer to individual species.

Table 3

Species and species groups of fish identified in samples of shrimp by-catch collected from the central Gulf of California during August 1977-April 1978. (Relative frequency (R.F.)= no. of samples containing species/total no. of samples.) (Order of observation throughout season) (From Young and Romero, 1977)

Scientific name	Common name	Mean weight (g)	Mean length (cm)	No. of organisms observed	R.F.
Eucinostomus spp.	mojarras	35	11	1 734	0.85
Orthopristis reddingi Jordan and Richardson	bronze-striped grunt	50	11	335	0.64
Scorpaena spp.	scorpionfishes	21	9	250	0.49
Citharichthys spp and/or *Etropus* spp.	flatfishes	20	9	1 190	0.77
Paralabrax maculatofasciatus (Steindachner)	spotted sand bass	113	18	62	0.40
Paralonchurus goodei Gilbert	carvina	86	14	37	0.19
Calamus brachysomus (Lockington)	Pacific porgy	242	19	67	0.40
Rhinobatos productus Ayres and/or *R. glaucostigma* (Jordan and Gilbert)	shovelnose guitar-fishes	277	34	45	0.36
Umbrina xanti Gill	croaker	138	20	20	0.02
Galeichthys cuerulescens (Günther)	chihuil catfish	150	20	121	0.60
Porichthys spp.	midshipmen	30	12	229	0.57
Pleuronichthys ritteri Starks and Morris	turbot	50	15	29	0.19
Prionotus ruscaris (Gilbert and Starks)	searobin	45	10	119	0.43
Balistes polylepis Steindachner	finescale trigger-fish	387	30	27	0.28
Rhizorpionodon longurio (Jordan and Gilbert)	Pacific sharpnose shark	301	36	150	0.17
Diplectrum spp.	cabaicuchos	52	13	977	0.68
Synodus scituliceps Jordan and Gilbert	sharpnose lizard-fish	126	19	116	0.55
Decodon melasma Gomon	wrasse	73	15	10	0.15
Narcine entemedor Jordan and Starks	torpedo ray	363	26	5	0.11
Chaetodipterus zonatus (Girard)	Pacific spadefish	63	12	3	0.02
Bairdiella icistia (Jordan and Gilbert)	Bairdiella	150	16	109	0.34
Scomber japonicus Houttuyn	Pacific mackerel	95	19	12	0.17
Ophichthus zophochir (Jordan and Gilbert)	spotted snake eel	168	46	4	0.06
Cheilotrema sp.	croaker	210	21	2	0.02
Haemulon scudderil Gill	grunt	146	18	5	0.06
Caulolatilus affinis Gill	blanquillo	241	22	8	0.09
Trachinotus sp.	pompano	242	20	4	0.09
Mugil cephalus Linnaeus	striped mullet	140	22	2	0.02
Opistognathus punctatus Peters	finespotted jaw-fish	150	19	4	0.09
Sphoeroides annulatus (Jenyns)	bullseye puffer	51	11	59	0.21
Urolophus halleri Cooper	round stingray	250	29	2	0.06
Nematistius pectoralis Gill	roosterfish	70	14	1	0.02
Lutjanus argentiventris (Peters)	yellow snapper	150	18	1	0.02
Euthynnus pelamis (Linnaeus)	skipjack	200	21	1	0.02
Fistularia corneta Gilbert and Starks	cornetfish	210	42	2	0.06
Umbrina roncador Jordan and Gilbert	yellowfin croaker	190	20	8	0.09
Pseudupeneus grandisquamis (Gill)	red goatfish	37	12	198	0.45
Albula vulpes (Linnaeus)	bonefish	135	22	2	0.04
Selene brevoortii (Gill)	Mexican lookdown	11	6	13	0.13
Hoplopagrus guentheri Gill	barred pargo	50	10	6	0.06
Achirus mazatlanus (Steindachner)	Mazatlan sole	39	8	45	0.34
Micropogonias altipinnis (Günther)	Gulf croaker	15	8	233	0.17
Polydactylus opercularis (Gill)	yellow bobo	65	14	2	0.04
Peprilus sp.	palometa	91	14	95	0.32
Myrichthys tigrinus Jordan and Gilbert	tiger snake eel	260	62	1	0.02
Cynoscion xanthulus Jordan and Gilbert	orangemouth corvina	104	18	62	0.28

Table 3 (continued)

Scientific name	Common name	Mean weight (g)	Mean length (cm)	No. of organisms observed	R.F.
Hypsopsetta guttulata (Girard)	diamond turbot	75	14	4	0.09
Scomberomorus sierra Jordan and Starks	sierra	110	22	1	0.02
Opistognathus snyderi (Jordan and Evermann)	jawfish	140	19	1	0.02
Anchoa sp.	anchovy	19	10	222	0.28
Xenistius californiensis (Steindachner)	salema	91	14	339	0.23
Xystreurys liolepis Jordan and Gilbert	fantail sole	79	15	13	0.06
Paralichthys woolmani Jordan and Williams and/or *P. aestuarius* Gilbert and Scofield	halibut	338	25	5	0.04
Heterodontus francisci (Girard) and/or *H. mexicanus* Taylor and Castro-Aguirre	horn shark	20	13	1	0.02
Lepophidium sp. and/or *Otophidium* sp.	Cusk eel	54	22	38	0.21
Bothus spp.	flatfish	10	8	2	0.04
Mustelus spp.	smoothhound sharks	372	37	5	0.04
Lutjanus guttatus (Steindachner)	spotted rose snapper	66	12	11	0.09
Lutjanus peru (Nichols and Murphy)	red snapper	180	19	3	0.06
Paralabrax auroguttatus Walford	goldspotted sand bass	182	18	47	0.06
Squatina californica Ayres	Pacific angel shark	394	21	7	0.15
Bellator xenisma (Jordan and Bollman)	searobin	15	7	3	0.06
Orthostoechus maculicauda Gill	grunt	102	16	50	0.13
Hippoglossina tetrophthalmus (Gilbert)	fourspot sole	96	18	5	0.11
Pomadasys panamensis (Steindachner)	grunt	150	12	15	0.15
Lythrulon flaviguttatum (Gill)	Cortez grunt	340	25	1	0.02
Polydactylus approximans (Lay and Bennett)	threadfin	40	12	1	0.02
Zapteryx exasperata (Jordan and Gilbert)	guitarfish	-	-	1	0.02
-	ray	190	16	1	0.02
Microlepidotus inornatus Gill	wavyline grunt	350	26	2	0.02
Symphurus spp.	tonguefishes	17	14	16	0.19
Sphyraena argentea Girard	California barracuda	-	-	-	-
Gymnothorax equatorialis (Hildebrand)	moray eel	270	65	1	0.02
Sardinops sagax caerulea (Jenyns)	Pacific sardine	63	16	76	0.19
Urotrygon spp.	rays	170	24	4	0.04
Paralichthys aestuarius (Gilbert and Scofield)	halibut	200	19	11	0.13
Urolophus spp.	rays	260	25	9	0.06
Lophiomus setigerus (Vahl)	goosefish	26	7	5	0.09
Myrophis vafer Jordan and Gilbert	estero worm eel	15	22	2	0.04
Epinephelus acanthistius (Gilbert)	Gulf coney	30	8	1	0.02
Ophichthidae	snake eel	240	52	2	0.04
Oligoplites saurus (Bloch and Schneider)	leatherjacket	40	14	1	0.02
Trichiurus nitens Garman	Pacific cutlassfish	23	32	3	0.06
Bollmarinia sp.	goby	10	7	132	0.11
Larimus pacificus Jordan and Bollman	Pacific drum	75	15	2	0.04
Haemulopsis leuciscus (Günther)	grunt	52	14	32	0.04
Hemicaranx leucurus (Günther)	jack	70	14	1	0.02

Table 4

Summary of Gulf of Mexico fish by-catch including mean ratio, by-catch estimates (in t), and species compositions (expressed as percent by weight). (Source: Pellegrin, Drummond, and Ford, MS in preparation) (From Pellegrin, 1982)

Name	% of total finfish	Estimated by-catch (t)
Micropogon undulatus	29.1	163 639
Leiostomus xanthurus	6.0	33 740
Cynoscion arenarius	5.0	28 117
Synodus foetens	3.5	19 682
Stenotomus caprinus	3.4	19 119
Cynoscion nothus	3.3	18 557
Syacium gunteri	3.1	17 432
Lagodon rhomboïdes	2.9	16 308
Prionotus rubio	2.7	15 183
Arius felis	2.3	12 934
Overall F/S = 9.1		
Total by-catch = 560 939		

Table 5

Summary of South Atlantic fish by-catch including mean ratio, by-catch estimates (in t), and species compositions (expressed as percents by weight). (From Pellegrin, 1982)

Name	% of total finfish	Estimated by-catch (t)
Leiostomus xanthurus	28.2	10 388
Micropogon undulatus	15.4	5 685
Cynoscion regalis	3.7	1 368
Brevoortia tyrannus	3.7	1 355
Menticirrhus sp.	3.7	1 354
Orthopristis chrysoptera	3.0	1 088
Stellifer lanceolatus	2.1	778
Paralichthys lethostigma	1.4	518
Arius felis	1.4	499
Non-foodfish flounder sp.	1.1	402
Overall F/S = 2.8		
Total by-catch = 36 878		

Table 6

Marine production, by-catch and small pelagic fish
in Thailand (1976-80)
(From Saisithi, 1982)

Year	Marine production (t)	By-catch		Small pelagic fish	
		Quantity (t)	Percentage	Quantity (t)	Percentage
1976	1 551 798	620 646	40.00	105 692	6.81
1977	2 067 533	836 643	40.47	214 077	10.35
1978	1 937 785	847 412	42.28	145 278	7.42
1979	1 813 158	784 267	43.25	161 890	8.92
1980	1 500 000*	648 750*	43.25*	134 955*	9.00*

*Estimated figures

Table 7

By-catch, small pelagic fish used for fish meal production
in Thailand (1971-80)
(From Saisithi, 1982)

Year	Landing (t)		Quantity (t) and percentage for fish meal production			
	By-catch	Small pelagic fish	By-catch		Small pelagic fish	
			Q	%	Q	%
1971	653 329	28 404	304 610	46.48	5 671	19.69
1972	719 091	11 376	365 380	50.88	2 275	20.00
1973	804 478	34 285	458 870	57.04	3 857	20.00
1974	690 870	58 222	450 297	65.24	11 644	20.00
1975	634 971	63 522	537 976	80.00	12 704	20.00
1976	620 645	105 692	496 516	80.00	21 124	19.99
1977	836 843	214 077	690 914	82.58	42 815	20.00
1978	847 412	145 278	829 131	97.84	58 111	40.00
1979	784 267	161 890	769 279*	88.09*	42 989*	26.56*
1980	648 756*	134 955*	642 262*	09.00*	33 738*	25.00*

*Estimated figures

Table 8

(From Subasinghe, 1982)
Shrimp by-catch landings in the two main areas of shrimp production in Sri Lanka (in t)

Area	Qty of shrimp landed	Shrimp by-catch	Qty of by-catch utilized	Qty of by-catch discarded	% of by-catch utilized
Jaffna	1 132	15 000	1 500	13 500	10
Mannar	785	10 000	2 500	7 500	25

As shown in Table 1, only 10-15% of the by-catch is commercially utilized. In the Mannar area (NW) the by-catch is mainly utilized for fish meal.

Table 9

Catches of shrimp and prawns by zones[a/] - 1978 and [b/] approximate fish by-catch (in t)
(From Allsopp, 1982)

Zone			
31	West Central Atlantic	48 153	723 000
34	East Central Atlantic	16 602	249 000
37	Mediterranean	5 077	45 900
41	Southwest Atlantic	46 943	703 500
47	Southeast Atlantic	1 557	24 000
51	W. Indian Ocean	215 580	3 233 700
57	Eastern Indian Ocean	46 642	699 000
61	Pacific Northwest	138 835	1 249 200
67	Pacific Northeast	1 569	14 400
71	W. Central Pacific	304 275	4 564 500
77	E. Central Pacific	53 797	807 000
81	Australia	2 430	21 600
	Grand Total:	881 460	12 273 800

a/ Source: FAO 1978 Yearbook of Fishery Statistics

b/ Note: The approximate figures of fish by-catch are obtained by estimating the average quantity of total fish by-catch discard ≠ by-catch in most Asian countries to be 15:1 in tropical areas and 9:1 in temperate areas. These figures therefore, include both the edible marketable species and unutilized types which may be used for industrial purposes

Table 10

Average percentage loss in weight of all species combined due to mesh selection and cull selection for each of the four mesh sizes used in the analysis. (From Mayo et al., 1981)

Northwest Atlantic Region

Fishery	Mesh (mm)	Mesh selection % escapement	Cull selection % discard
15	45	0.24	48.34
2	64	0.86	65.92
5	64	0.60	16.46
7	64	1.47	20.96
8	64	3.67	44.37
10	64	1.46	23.82
20	64	1.37	64.41
21	64	3.46	77.17
22	64	8.54	0.00
23	64	6.53	49.72
24	64	0.40	63.25
Average		2.84	42.61
4	102	10.87	26.92
6	102	21.71	26.09
17	102	12.77	28.39
18	102	6.89	33.24
25	102	16.49	68.23
26	102	15.91	76.05
27	102	5.88	78.94
Average		12.93	48.27
1	130	29.90	18.31
3	130	9.61	14.23
9	130	41.08	71.66
11	130	32.09	66.14
12	130	33.62	50.53
13	130	22.34	13.92
14	130	30.33	30.26
16	130	33.51	46.99
19	130	29.50	21.17
28	130	10.43	62.55
29	130	15.30	46.13
Average		26.16	40.17

Table 11

Discard rates and standard errors by species and gear
1975-80 (based on individual boat data)
(From Jermyn and Robb, 1981)

	Seine				Trawl			
	Discard rate (by weight)	SE	Discard rate (by numbers)	SE	Discard rate (by weight)	SE	Discard rate (by numbers)	SE
Haddock								
1975	0.42	±0.07	0.62	±0.06	0.24	±0.09	0.42	±0.09
1976	0.30	±0.04	0.50	±0.05	0.16	±0.02	0.29	±0.02
1977	0.19	±0.03	0.36	±0.04	0.15	±0.03	0.26	±0.04
1978	0.27	±0.04	0.49	±0.05	0.22	±0.05	0.38	±0.06
1979	0.29	±0.03	0.51	±0.04	0.18	±0.04	0.37	±0.05
1980	0.48	±0.03	0.59	±0.04	0.27	±0.04	0.43	±0.06
Whiting								
1975	0.32	±0.06	0.45	±0.06	0.18	±0.03	0.30	±0.03
1976	0.31	±0.05	0.45	±0.06	0.17	±0.03	0.26	±0.04
1977	0.33	±0.05	0.50	±0.05	0.10	±0.05	0.21	±0.07
1978	0.15	±0.03	0.23	±0.03	0.29	±0.02	0.37	±0.03
1979	0.14	±0.03	0.23	±0.04	0.18	±0.07	0.26	±0.09
1980	0.27	±0.06	0.38	±0.06	0.28	±0.07	0.42	±0.09
Cod								
1975	0.11	±0.02	0.48	±0.06	0.001	±0.001	0.01	±0.01
1976	0.08	±0.02	0.29	±0.04	0.01	±0.01	0.05	±0.03
1977	0.13	±0.04	0.54	±0.06	0.02	±0.02	0.10	±0.05
1978	0.10	±0.04	0.28	±0.08	0.01	±0.01	0.09	±0.03
1979	0.04	±0.05	0.18	±0.05	0.01	±0.01	0.05	±0.02
1980	0.14	±0.03	0.46	±0.05	0.01	±0.01	0.06	±0.03

APPENDIX 10

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